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REDUNDANT SENSOR STRAPDOWN IMU EVALUATION
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ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

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DETAILED TEST PLAN
REDUNDANT SENSOR STRAPDOWN IMU
EVALUATION PROGRAM

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1. INTRODUCTION

This Detailed Test Plan is submitted to NASA MSFC as the third and final report on Contract NAS-8-27335. This plan defines the details of the test series comprising the MSFC redundant sensor strapdown IMU evaluation experiment. It is to be used in conjunction with the General Test Plan, Redundant Sensor IMU Evaluation Program, Reference 5.

1.1 SCOPE

This plan contains details of test conditions, test requirements, operating procedures, and data and analysis requirements. Additional information contained in the Redundant Sensor Program documentation, References 1 through 6, is required for successful completion of this program.

This plan establishes the total test sequence (test duration, input/output, and environmental conditions) and typical equipment operating procedures from which detailed test procedures can be written as required.

2. GENERAL TEST DISCUSSION

2.1 TEST PHILOSOPHY

This test series is a first demonstration of an integrated redundant strapdown navigation system using the SAR gyro mechanization. It is primarily a feasibility demonstration with a limited measurement of performance data. The recorded sensor data from a mobile van will provide real dynamic sensor inputs to the redundant sensor navigation program.

This test series was planned as the first step in a test program that would ultimately include an improved IMU, more advanced failure detection logic, and greater accuracy.

2.2 LIMITATIONS

Performance in this prototype test program will be limited by:

a. Inherent performance of the modified Saturn gyros

b. Lack of temperature control

c. Partial compensation for the SAR error model.

The program does not involve detailed dynamic error modeling or testing.

2.3 ACCURACY

From Table 3-I of Reference 5, the expected system accuracy in the proposed tests is on the order of 5 n. mi. /hr (1 n. mi. /hr in stationary tests.)

2.4 TEST SEQUENCE

A complete checkout of the calibration, alignment, and navigation subroutines will first be accomplished without failures. The principal test phase, failure detection diagnosis and correction (FDDC) demonstration, will then repeat the alignment and navigation tests with failures. Inputs shall be both real time and recorded (van) data.

The given nominal test sequences are intended to be very flexible with deviations to be dictated by the progress of the experiment.

3. EQUIPMENT DISCUSSION

3.1 GENERAL

The equipment and interface definitions are contained in References 2 and 5. Some significant features and additions are described here.

3.2 SOFTWARE STATUS

The RS program for this test program shall be the program as documented in References 3 and 4, and as modified by:

a. Subsection 4.1 of Reference 5

b. Appendix D of this plan.

The significant changes reflect revisions to:

a. Geodetic constants

b. Sensor output format

c. Fixture configuration

d. Operating procedures

e. FDDC filter constants

f. Altitude damping constant

g. Calibration static test time.

3.3 TEST SITE COORDINATES

The geodetic constants for the Astrionics inertial test lab are:

a. Geodetic latitude 34° 36' 51"

b. Geodetic longitude 86° 40' 11"

b. Local gravity 32.139929 ft/sec^2

3.4 BB DDH CONFIGURATION

Provision has been made for the addition of three angular vibration sensors to the BB DDH configuration defined in Subsection 2.1 and Figure 5-2, Reference 5.

The correspondence of the old (ERC) and the new (MSFC) nomenclature for the sensors is given in Table 3-I. The RS program documentation uses the ERC nomenclature.

Table 3-I. MSFC and ERC Nomenclature

	MSFC	ERC
Gyros	X1	D
	X2	-C
	Y1	E
	Y2	-F
	Z1	A
	Z2	-B
Accelerometers	X	C
	-	D
	Y	E
	-	F
	Z	A
	-	B

3.5 LABORATORY TEST CONFIGURATION

The test configuration in Figure 3-1 is revised from Reference 5, by the addition of a link between the analog tape reproduce electronics and the SAR gimbal position monitor (counters). This will permit a record/reproduce quality check as described in Subsection 9.3.

3.6 VAN TEST CONFIGURATION

Figure 3-2 is a block diagram of the van recording setup. The gimbal zero pulses need not be recorded as shown if the abbreviated procedure of Paragraph 9.3.2 is used.

In addition to the instrumentation shown, a fifth wheel may be attached to the van to record velocity and distance. This would be more convenient and more accurate than using the speedometer of the towing vehicle, but it is not mandatory.

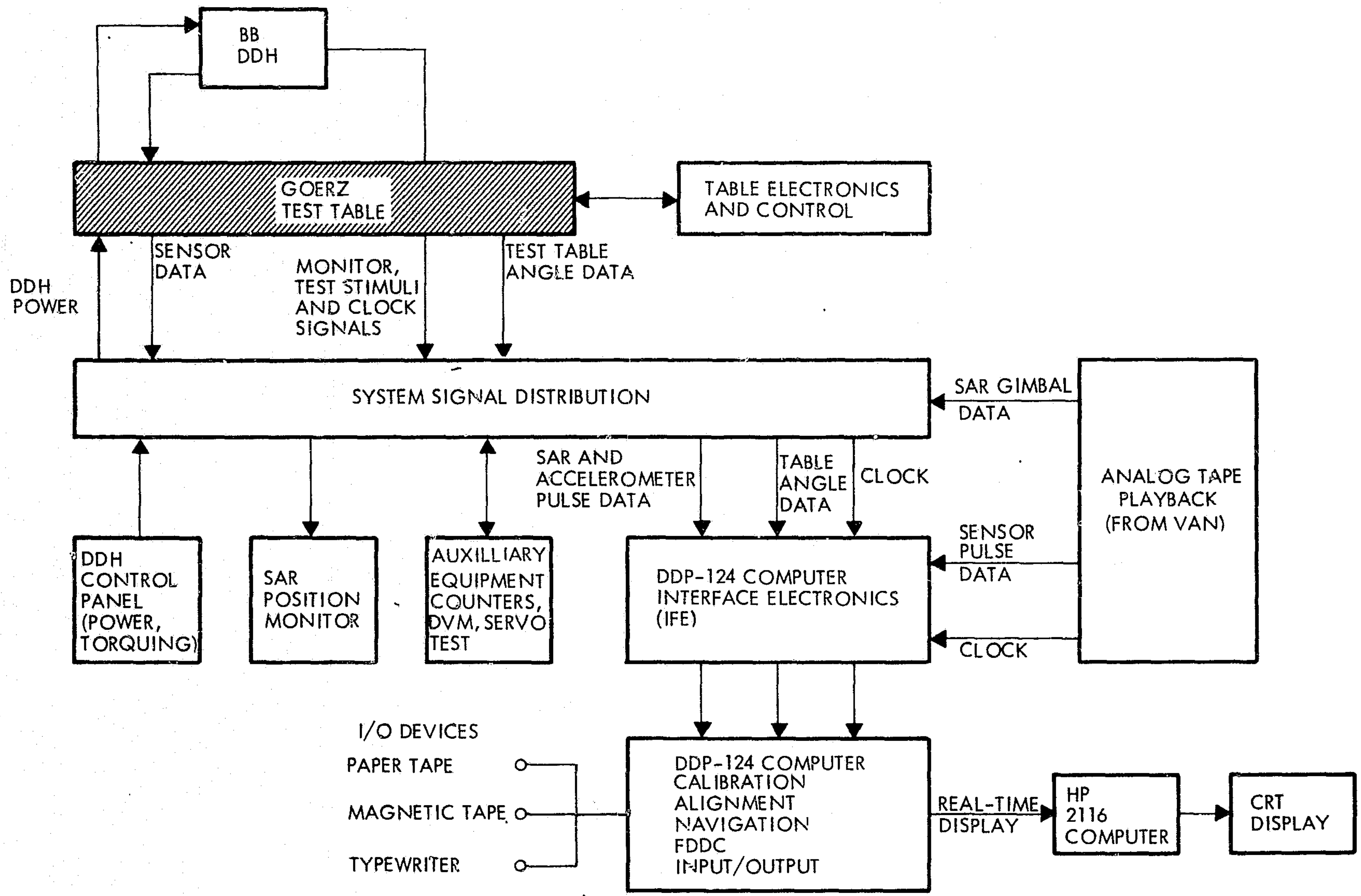

Figure 3-1. Laboratory Test Block Diagram

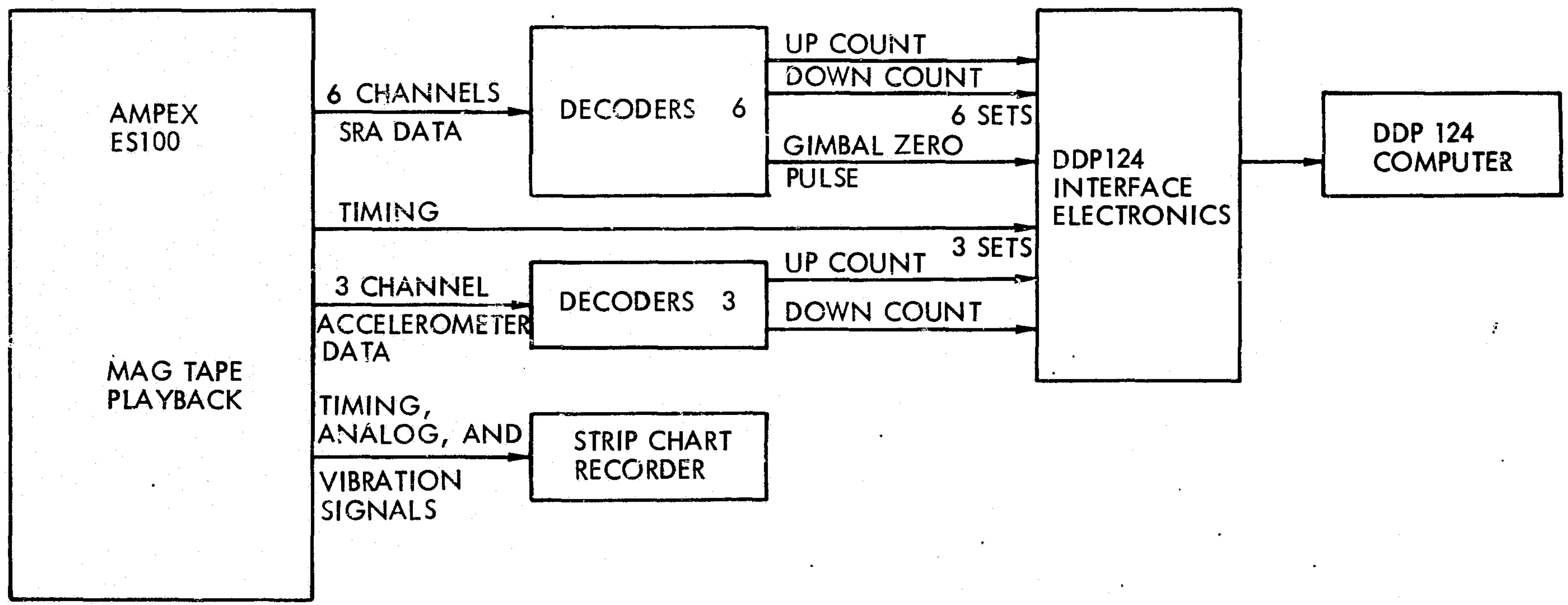

Figure 3-2. Van Test Tape Reproduce Configuration (Conceptual)

4. GENERAL OPERATING PROCEDURES

4.1 OPERATING PROCEDURES

The information required to operate the RS program with the BB DDH hardware, Interface Electronic Equipment (IFE) and DDP 124 computer is described in this section.

A system block diagram of the RS system is presented in Figure 3-1. The gyro and accelerometer output pulses and table angle pulses are accumulated in the registers of the IFE and the accumulated counts are transferred to the DDP 124 computer under the control of the IFE generated interrupt signal, INTO3. The INTO3 signal is generated when the accumulated count of clock pulses exceeds a predetermined number. The predetermined number and clock rate are set such that INTO3 will be generated every 40 msec. The RS program inputs the accumulated pulse information, performs various computations, and outputs information on the real-time display or other output devices.

To process the accomulated pulse date, the DDP 124 computer must be loaded with the proper RS program and input data. The input data are required to specify the particular program operations desired (such as calibration, navigation, or alignment).

To load the RS object program, the normal procedure for the loading of any object tape should be followed. The object tape of the RS program and the DDP 124 system tape are required for the operation. The loading procedure is described in the DDP 124 Users Guide (Honeywell Document No. 130071543) and Paragraph 4.2.1.

After the loading of the program, various run parameters and flags must be input to control the operation of the program. These data are input with the use of a subroutine called Read/Write subroutine (RDWT S/R). Details of the Read/Write subroutine are contained in Volume II, Section 3 of Reference 3.

4.2 COMPUTER OPERATING PROCEDURES

This section defines the sequence of computer operating procedures required to run the RS program in the various modes of operation. The basic knowledge regarding the operation of the DDP 124 computer is assumed. For real-time operation, the BB DDH should be interfaced with the computer through the Interface Electronic Equipment as described in Reference 2.

In the following sections, general operation procedures common to all of the modes of program operations are described, followed by specifics for each mode of operation.

4.2.1 Program Loading

To load the program, the following materials are needed:

a. BOOT paper tape

b. System tape with the Loader program and subroutines

c. Object tape of the RS program.

The loading procedure is:

a. Turn on the typewriter and paper tape reader and insert the BOOT paper tape in the reader.

b. Mount the system tape on logical unit 0.

c. Press MASTER CLEAR, set FILL/HALT/RUN to FILL and EXECUTE/OFF/FETCH to OFF, and press START. The BOOT paper tape will be read at this time

d. Press MASTER CLEAR again, set FILL/HALT/RUN to RUN, and press START. The system tape DOPD program will be read and the typewriter will type SELECT.

Note: If the DOPD program was loaded previously and was not destroyed, the following simpler procedure may be used:

1. Mount the system tape on Logical Unit 0.

2. Press O&P pushbutton of the Register Select buttons, press MASTER CLEAR, and key in the starting location of the DOPD program (00037400).

3. Set EXECUTE/OFF/FETCH to OFF and FILL/HALT/RUN to RUN and press START. The typewriter will type SELECT.

e. Type the name of the Loader program (LOAD2), and hit the carriage return. The Loader program of the system tape will be read into the memory, and the typewriter will type READY.

f. Mount the object tape on Logical Unit 1.

g. Set the A register to this octal pattern, 00040200.

h. Press START. The object tape will be loaded. The typewriter will type MORE. Press START again and subroutines from the system tape will be read. The typewriter will type DONE after the completion of program loading. The load map will be output to the typewriter.

This completes the program loading procedure.

4.2.2 Program Initialization

After the above loading operation, the program is ready to start at the starting location (100_8). (If the program was loaded previously and the program is being restarted, depress the O&P pushbutton and key in 00100 into the address portion of the register.) Depressing the START button at this time will initiate the program execution. The program will initialize the temporary storage of the memory and the typewriter will print out the following message:

SELECT IN/OUT UNIT AND PRINT FREQ

At this time, the operator will type in his selection of input/output devices and print frequencies according to the format specified in Paragraph 4.2.6.1. Hitting the carriage return will result in the following message on the typewriter:

NEW OUTPUT LIST OR OLD

Before typing *NEW and hitting the carriage return, a list of desired output words should be ready to be read at the specified input device. The format is described in Paragraph 4.2.6.2. A properly formatted list of main program inputs should follow the output parameter word list. The contents of these lists depend on the program mode desired and what the user wishes to do and investigate. The program mode will be selected during the main program input sequence. The details of these program inputs and outputs are described in Sections 5 through 8.

4.2.3 Sense Switch Settings

After the completion of the main program input, control is transferred to the main program and the execution of the program commences. (In the case of the Driver mode, there is another input sequence called phase input.) By this time, the sense switches should be set properly for the operation desired. The sense switch settings used by the program in various modes of operations are described below.

4.2.3.1 Sense Switch Settings and Operating Procedure for Calibration Program

A detailed description of the Calibration program is presented in Section 5. This section describes the operator-computer interactions with the sense switches and the computer-console display during a calibration operation.

The Calibration program uses the sense switch settings in two phases. The first phase uses Sense Switches 1, 2, and 3 as follows:

Table 4-I. Calibration Program Sense Switch Settings

	SS_1	SS_2	SS_3
Rate table test	1	X	0
Static table test	0	1	0
Rate table test computation only	1	X	1
Static table test computation only	0	1	1

"X" indicates the switch may be up (1) or down (0).

When Sense Switch 3 is set to 1, the pulse data accumulation of the program is skipped and the computations for the gyro or accelerometer scale factors, biases, and direction cosines are performed. In this case, the program assumes that the data needed for the computation are already stored in memory either by the main program input or some other method.

When Sense Switch 3 is 0, the program proceeds to the pulse data accumulation process. The program stores the information regarding which test is to be performed and then waits for the operator to set the sense

switches for a particular table orientation or rotation. All six sense switches are used for this purpose and their assignments are as follows:

Table 4-II. Rate Table Test Switch Assignment

Table Orientation	Rotation	Sense Switches					
		SS_1	SS_2	SS_3	SS_4	SS_5	SS_6
X axis up	Positive	1	X	X	X	X	X
	Negative	0	1	X	X	X	X
Y axis up	Positive	0	0	1	X	X	X
	Negative	0	0	0	1	X	X
Z axis up	Positive	0	0	0	0	1	X
	Negative	0	0	0	0	0	1

Table 4-III. Static Table Test Switch Assignment

Table Orientation	Sense Switches					
	SS_1	SS_2	SS_3	SS_4	SS_5	SS_6
X axis up	1	X	X	X	X	X
X axis down	0	1	X	X	X	X
Y axis up	0	0	1	X	X	X
Y axis down	0	0	0	1	X	X
Z axis up	0	0	0	0	1	X
Z axis down	0	0	0	0	0	1

After setting the sense switch to the table configuration selected, and after observing the table rotation achieve a steady rate for the rate table test, the operator depresses the START button of the DDP 124. The sampling of pulses starts immediately at 1-msec intervals, and is terminated when the total table rotation equals 360 deg for the rate table test, or when the total sampling time equals 240 sec for the static table test.

The accumulated pulses for a particular table configuration are stored in appropriate locations and the corresponding bit of the table flag (CTFG) is reset. If CTFG is not all 0's, the flag is displayed on A register of the console and the program is halted. The purpose of this display is to show the operator which table configurations are not completed.

The bit assignment of the CTFG flag and the corresponding A register bit configuration are as follows:

Table 4-IV. Calibration Program — CTFG Flag and A Register Bit Configuration

A Register Bit	CTFG Bit	Rate Test		Static Test
		Axis Up	Rotation	
18	1	X	+	X up
19	2	X	-	X down
20	3	Y	+	Y up
21	4	Y	-	Y down
22	5	Z	+	Z up
24	6	Z	-	Z down

A 1 or light on the A register display indicates an incomplete table configuration. At the program halt, the operator may choose any of the six table configurations. If he chooses one which he already has performed, he will be replacing the previous data with new data.

If the flag CTFG is all 0's after a sampling and store sequence is completed, the program performs the calibration computations and the C matrix generation immediately and types out the results according to the format requested at the beginning.

Depressing the START button after the printout will result in storing the newly computed sensor constants in the main program. During this process, various sensor constants and direction cosines are converted to the main program units and scalings.

When both calibration tests are completed, the main program will contain all the necessary sensor constants.

4.2.3.2 Sense Switch Settings for Other Modes (Noncalibration)

For all modes of operations other than the calibration program, Sense Switches 1 and 2 are used in the FDDC routine, and Sense Switches 3 and 4 are used for the real-time display options. Sense Switch 5 is used in the real-time mode to output data to a magnetic tape and Sense Switch 6 is used for the on-line change options during the simulation modes (Driver input or tape input). (See Subsection 4.3.) In the real-time mode, Sense Switch 6 is used to disable the interrupts and stop (see Appendix D). At this point, the operator may leave Sense Switch 6 on and push the START button. The Read/Write subroutine is entered and the "TDMP" option can be selected. This will dump all those words selected by the OPW list onto the typewriter. After this dump, the computer will halt. If the START button is pushed, the Read/Write subroutine is entered again; and an OPW list will be read and then listed on the selected output device. This pattern can be repeated as often as desired.

If the Sense Switch 6 option is used in the real-time mode, and if Sense Switch 6 is then set off when the computer halts and the START button is pushed, the program will enter the Read/Write subroutine. At this time, the operator will have a chance to select an output device and then read in a set of OPWs. Then the specified words will be listed on the selected output device. This logic may be repeated as often as desired.

These functions of Sense Switch 6 presume the program changes identified in Appendix D have been implemented.

Real-time display control by Sense Switches 3 and 4 is discussed in Subsection 7.4 for the navigation mode and Subsection 6.4 for the alignment mode.

Sense Switches 1 and 2 are used by the FDDC subroutine to control the modes of operations as shown in Table 4-V.

Table 4-V. FDDC Subroutine — Sense Switches 2 and 3 Settings

	Sense Switch	
	SS_1	SS_2
Output Comparison only	0	1
Internal Monitor only	1	0
Output Comparison and Internal Monitor	1	1

When both Sense Switches 1 and 2 are 0's (not set), the program halts in the FDDC subroutine. For the simulation mode of operation, the sense switches may be set properly at this time. The program will proceed normally by depressing the START button. For the real-time mode of operation, the interrupt signal will cause problems. The program should be restarted with the proper sense switch settings.

4.2.4 Modes of Operation

Program major modes of operation are determined by the settings of 3 flags which are input during the main program input sequence. Their settings for all modes of operations are listed below:

Table 4-VI. Program Flag Settings

Mode of Operation	Flag Setting		
	CALF	DRVE	ALGN
Calibration	1	X	X
Navigation with Driver	0	1	0
with Tape Input	0	-1	0
with BB DDH	0	0	0
Alignment with Driver	0	1	1
with Tape Input	0	-1	1
with BB DDH	0	0	1

"X" denotes these flags are not checked.

For a more complete listing of program flags, see Table 4-XI.

The operating procedure for the calibration program was discussed in Paragraph 4.2.3.1. This section describes the operation procedures for the other six modes of operations.

4.2.4.1 Navigation with Driver

After the main program input sequence, during which the proper flags and data are input, control is returned to the Driver program. The first thing the Driver program requests is the phase input data for the first phase. Therefore, the phase input data should be ready to be read in with the specified input device. For the Driver mode of operation, a strip of paper tape containing the OPW formats, the main program inputs, the first phase inputs, the second phase inputs, and so on, can be prepared with the proper END codes at the end of each block of data. This strip of paper tape can be kept on the paper tape reader. As additional data are required, the program will read the data and proceed. The run will be terminated when the processing for the last phase is completed and no additional phase data are available.

Output during the Driver mode of operation may be sent to the typewriter or magnetic tape. Selection is performed as described in Paragraph 4.2.6.1. Output on magnetic tape is in a BCD format and can be processed by the data reduction facilities as a print tape.

The real-time display may be employed to display a set of parameters selected by the sense switches. For the list of parameters and the corresponding sense switch settings, refer to Sections 6 and 7.

When the output operation is done only on magnetic tape and the real-time display is not available, the progress of program processing may be monitored by using the Sense Switch 6 option described in Subsection 4.3.

4.2.4.2 Navigation with Tape Input

The inputs used by the navigation program during the Tape Input mode of operation will be read from the Magnetic Tape Unit 1. For each sampling interval, the input data should consist of six sets of gyro pulses, three sets of accelerometer pulses, the table angle rotation pulses, a discrete input word, and four spare words. The order of these input data must be

the same as that described in Table B-5 of Appendix B, Volume I, Reference 3. The first 14 input words are used by the program. The sampling frequency with which the data are recorded on the input magnetic tape must be an integral multiple of the normal minor cycle frequency (25 Hz). See Appendix C.3 for input tape format.

The recording frequency information must be read into the program during the main program input sequence. The number corresponding to the integral multiple of the frequency is input as follows:

Field One	(Columns 2-5)	:	263
Field Two	(Columns 7-9)	:	23
Field Three	(Columns 11-14)	:	RCT
Field Four	(Columns 16-30)	:	n.

The n above is the integral multiple. It should be set to 1 for 25-Hz recording, 2 for 50-Hz recording, etc.

Depending on the number n input, the program adds n blocks of data and assembles the pulse data equivalent for a 40-msec sampling frequency.

The rest of the operation is similar to the Driver mode of operation. The failure simulation option and all the output options may be exercised during the Tape Input mode of operation. The only difference from the Driver mode of operation is that the phase input data are not required since the Driver program is bypassed completely.

4.2.4.3 Navigation with Sensor Input

To perform the Navigation mode of operation with the BB DDH sensor inputs, the sensor assembly, the Interface Electronic Equipment, and the DDP 124 computer should be connected as specified in the Interface Definition, Section 3, Reference 2.

The toggle switch settings of the IFE should be set to generate the INTO3 signal every 40 msec as specified in Subsection 3.4 of Reference 2.

The output operation during the Sensor Input mode (the real-time mode) of operation is limited. Up to 20 words of output are allowed to be recorded on a magnetic tape for each minor cycle. Up to 60 output words are allowed for a major cycle output. All of these data are recorded in binary form.

The progress of a navigation operation may be monitored on the real-time display. The settings of the sense switches to select a set of parameters to be displayed are described in Sections 7 and 8.

The navigation program in the real-time mode of operationmay be terminated as a function of time (tg). The desired duration of time (or the stop time) in seconds is input to the program location called STPT during the initial main program input sequence. The details of inputs are as follows:

Field One	(Columns 2-5)	:	266
Field Two	(Columns 7-9)	:	15
Field Three	(Columns 11-14)	:	STPT
Field Four	(Columns 16-30)	:	XXX. XX

With this input, the real-time mode of operation will terminate XXX. XX seconds after the start of the run (after the completion of the main program input sequence). An end-of-file is written on the output magnetic tape and the program will stop.

At this time, a set of output parameter words may be read. To output the results of a run on the typewriter see Paragraph 4. 2. 3. 2 for a description of the Sense Switch 6 option.

4. 2. 4. 4 Alignment Mode of Operation

The differences between the Alignment mode of operation and the Navigation mode of operation is minor as far as the operating procedures are concerned The only difference is that the sets of parameters to be displayed on the real-time display are different from those for the navigation program. The selection of the real-time display parameters for the Alignment program is described in Paragraph 4. 2. 6. 5.

The IFE and BB DDH should be interfaced in exactly the same way as the Navigation mode for the real-time operation. Driver and Tape Input mode operations are also the same. Of course, the sensor assembly or the Driver program must be properly set up for an alignment operation. The input tape to be used for an alignment operation must have been generated with the sensor assembly properly configured for an alignment operation (see Appendix C. 3).

4.2.5 Tabular Summary of Operations

Operating procedures described in the foregoing sections are summarized below in a tabular form for the convenience of the users. Sequential operations that an operator must perform are tabulated here and detailed descriptions of the operations are referenced.

4.2.5.1 Initial Equipment Setup

a. Computer and peripheral equipment power on
DDP 124 Users Guide, Honeywell Document No. 130071543

b. BB DDH power on (for real-time mode)

c. IFE set up and power on (for real-time mode)
Appendix B, Vol I; Interface Electronics Option Manual, Honeywell Document No. 130071943

4.2.5.2 Program Loading

Subsection 4.2.

Depress START button after program loading.

4.2.5.3 Set Sense Switches for FDDC Options or for Calibration Test Selection

Paragraphs 4.2.3.1 and 4.2.3.2.

4.2.5.4 Program Initialization

a. Select input/output devices,
Paragraph 4.2.6.1

b. Output parameter words, Paragraph 4.2.6.2.

c. Main program input,
Paragraph 4.2.6.3

d. Driver phase input
Paragraph 4.2.6.3.

4.2.5.5 Program Execution

After the completion of the program input sequence, the execution of the program is automatically started. The mode of operation selected during the main program input is executed continuously until:

a. End conditions, which were also specified by the program input, are met (Navigation or Alignment mode);

b. Interrupted by Sense Switch 6 options, (see Paragraph 4.2.3.2) or halted by the program after the selection of calibration test (see Paragraph 4. 2. 3. 1).

The procedure for the Calibration program is entirely different from those of other modes of operations from this point on.

4. 2. 5. 6 Calibration

After the operations tabulated in Paragraph 4. 2. 5 are performed, the program will halt displaying 00016117_8 in the O/P register. (If the program is halted with 00016103_8 in the O/P register, then Sense Switches 1 and 2 both are not set. Set Sense Switch 1 and depress START. The program will halt with 00016117_8 in the O/P register.) The following procedures are to be followed to perform the rate table test:

a. Program halt with: O/P register 00016117_8
   A register 000111111_2

   Each bit of A register indicates an incomplete table rotation. Set up the table for any of the table rotation configurations, set the sense switches for that configuration, start the table, and depress START. (See Section 5.)

b. The program accumulates pulses for one complete rotation of the table, resets the bit corresponding to the table configuration just performed, and goes back to Paragraph a above, if the pulse accumulation for any table configuration is not completed.

c. If all six table configurations are completed, the computations for the rate table test are performed and the results are printed out on the specified output device (typewriter). The program will halt with 00016466_8 displayed on the O/P register.

d. If the results printed out are satisfactory, the calibration constants required will be converted and transferred to the main program. This process is initiated by depressing START.

e. After the completion of the rate table test data tranefer, the program will halt with 00016614_8 in the O/P register. At this time, the program is ready to accept the OPWs and other inputs for the static table test. Set Sense Switch 1 to 0 and Sense Switch 2 to 1 and depress START.

f. Operations described in Paragraphs 4.2.5.3 through 4.2.5.6 are performed for the static table test. The program selects the static table test and halts with the condition stated in Paragraph 4.2.5.6a.

g. Procedures described in Paragraphs a through e are performed for the static table test. The differences in procedure are:

   1. Sense switch settings and A register bit configurations for the static table test are different and are described in Paragraph 4.2.3.1.

   2. For operation b., no rotation of the table is involved. The program samples pulses for 240 sec.

   3. The O/P register display for the static table test for operation e. is 00016557_8. At this time, all the required calibration constants are in the main program. If START button is depressed, the program will enter the main program (see h below).

h. To enter the Navigation or Alignment program, prepare OPWs and the main program inputs on the input device to be selected, set Sense Switches 1 and 2 for the desired FDDC option, and depress START. Procedures described in Paragraphs 4.2.5.3 through 4.2.5.5 should be followed for the mode of operation selected.

4.2.6 Selection and Specification of Input/Output Data

Communication with the RS program by the operator is performed through a subroutine called the RDWT routine. The RDWT routine is a very flexible input/output program written for the RS program in FORTRAN IV. With this routine, the RS program constants and initial values of various variables are entered with any of the available DDP 124 input devices. Also with this routine, output parameter words (OPWs) are selected at the beginning of a run and printed or stored on a magnetic tape during the course of a run. The frequencies of printing or storing may be varied and the list of OPWs may be changed during a simulation mode run using the Sense Switch 6 option described in Subsection 4.3.

This section delineates the procedures required for communicating with the RS program with the RDWT routine. Some pertinent RS program operating procedure, input and output format specifications, and sense switch options are described.

4.2.6.1 Selection of Input/Output Devices

After the RS program and subroutines are loaded, the START button of the computer is depressed to start the program. The starting location of the program is octal location 100. The RS program will perform the initialization, and enter the RDWT routine. The RDWT routine requests operator inputs by typing:

SELECT IN OUT UNITS AND PRINT FREQ.

The following format statement is used to input the necessary information through the typewriter:

*A*B*CDEF*GHI*JKLM

The "*" means hit the space bar of the typewriter once. The letters A through M represent numerals 0 through 9. By typing the numbers, various input/output devices and output print frequencies are selected. Their assignments are described below:

Field One A (Column 2) specifies input device

Field Two B (Column 4) specifies output device

Field Three CDEF (Columns 6–9) specifies major cycle output frequency. (Number of minor cycles per major cycle output.)

For real-time operation, Field three is used to specify the tape output frequency. Even though tape output is done on a nearly continuous basis, the output control flag is tested only once per major cycle; therefore, if Field three is 0001, output will occur every major cycle. A 0009 will cause output to occur every other major cycle, etc.

For the Calibration program, there are no major and minor cycle distinctions. Field three for the Calibration program outputs should always be specified as 0001.

The above first three fields are mandatory inputs. The next two are optional:

Field four GHI (Columns 11-13) specifies that the first N OPWs are minor cycle OPWs. This applies only to the Driver mode.

Field five JKLM (Columns 15-18) specifies minor cycle output frequency.

For Field one and Field two, the following one-digit numbers are used to select the input/output devices:

1. Typewriter
2. Paper tape
3. Card reader
4. Line printer
5. Magnetic tape (tape unit one).

The following example selects the paper tape reader as the input device, the magnetic tape as the output device, major cycle output every 25 minor cycles, the first 18 words of OPW as minor cycle output, and minor cycle output after every minor cycle:

(A*B*CDEF*GHI*JKLM)	Field or column assignment
2 5 0025 018 0001	Actual typed input

Note that all fields must be right justified. After the above information is typed, the carriage return of the typewriter is depressed. The following is then typed by the RDWT routine:

NEW OUTPUT LIST OR OLD

At this time, one of the following three input words must be typed by the operator:

*NEW The program will now read a list of output parameters words (OPWs) from the specified input device. The previously read OPWs, if there are any, will be erased by this operation.

*OLD The program will now read a list of OPWs from the specified input device and adds the new list to the previous list.

*END No change to the OPW list is made by the program. This is used in conjunction with the Sense Switch 6 option described later.

4.2.6.2 OPW Format

After *NEW or *OLD is typed and the carriage return is hit, a list of OPWs is read and following the heading OUTPUT FROM RSSSTP, the

list of OPWs is output to the selected output device. The format for the OPWs to be input is as follows:

<u>One OPW</u>
*XXXX*YYY*ZZZZ

Up to six OPWs may be specified in a line. The total number of OPWs must not exceed 300. In real time, a maximum of 80 may be selected and the first 20 are automatically the minor cycle OPWs.

The description of the OPW format is as follows:

<u>Field One</u> XXXX (Columns 2-5, 15-18, 28-31, 41-44, 54-57, 67-70)

This field specifies the relative decimal location of the variable that is to be listed. The variable AZHT is defined to be at relative location one.

<u>Field Two</u> YYY (Columns 7-9, 20-22, 33-35, 46-48, 49-61, 72-74)

The binary scaling of the output variable.

<u>Field Three</u> ZZZZ (Columns 11-14, 24-27, 37-40, 50-53, 63-66, 76-79)

The name of the output variable. This field is used only for the purpose of identification with the following two exceptions. After the last OPW, the next Field three must contain the word END, left justified. Fields one and two should be set equal to 0. Also, to force the input routine to ignore a mistyped OPW, input a $ in the left-most column of Field three, the remainder of the field must be blank.

Table 4-VII is an example of OPW listings.

4.2.6.3 <u>Main Program Input</u>

After the last OPW, the heading information will be read by the input routine.* A field of 48 characters is allowed for the heading. If the first column contains a 1, a page skip will be given and then the heading information will be listed.

The main program input comes after the heading information. Various program flags to select the program modes as well as the initial values of variables are input to the program.

*Note: If input is via the paper tape reader, the program will halt to allow the operator to place the data tape in the reader.

Table 4-VII. Example of OPW Listing

F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3
410	15	F	861	15	TG	510	15	TP	407	23	NPHS	409	23	TIME	379	15	DLPN
435	3	WN	244	-11	WC	245	-10	WL	478	-16	WNDT	473	-16	WCDT	467	-15	WLDT
481	9	R2DV	482	9		483	9		462	6	GV	463	0	GE	464	0	GN
891	7	ALSV	892	7		893	7		504	8	ASNV	505	8		506	8	
474	-11	WV	475	-11	WE	476	-11	WNCP	545	6	GVP	543	0	GEP	544	0	GNP

F1: Field one, Relative location

F2: Field two, Scaling

F3: Field three, Name

The input format is as follows:

*XXXX*YYY*ZZZZ*WW----W

<u>Field One</u> XXXX (Columns 2-5)

This field specifies the relative decimal location of the variable which is to be initialized. Symbolic location AZHT is defined as relative location one. A negative location or a value greater than 1536 will cause the computer to stop. At this time, the A register can be corrected and when the START button is depressed, the processing of input data will continue.

<u>Field Two</u> YYY (Columns 7-9)

The binary scaling for the variable

<u>Field Three</u> ZZZZ (Columns 11-14)

The name of the input variable. This is for the purpose of identification only.

<u>Field Four</u> WW----W (Columns 16-30) G15.7 Format

The floating point decimal value to be input to the program. The 15.7 format allows for up to seven digits after the decimal point and either a decimal point or the exponential notation (E notation) or both may be used. If the E notation is used, it must be right justified within the field.

As many input values as needed may be specified. The order in which they are input is not important, and if a value is entered incorrectly it may be repeated. After a value is read in, it is listed on the specified output device. When the last value has been entered, a 0 value with END for the Field three must be input.

A sample list of input variables is presented in Table 4-VIII.

After the above END input is read and the carriage return is depressed, the control is returned to the RS program, and the initialization for various modes of operation specified by the input is performed. Except for the Driver modes of operation, no additional input is necessary, and the program starts processing the selected operations.

Table 4-VIII. Example of Main Program (Failure Simulation) Format

Relative Location	Scale	Symbol	Value
320	23	FX02	19.00000
322	23	FX04	20.00000
358	23	DMG1	1.000000
359	23	DMG2	21.00000
360	23	DMG3	421.0000
0	0	END	0.0000000E 00

4.2.6.4 Driver Phase Input

For the Driver mode of operation, the Driver program requires additional inputs when the Driver routine is executed for the first time or when the Driver phase is to be changed. These inputs are called the phase change inputs.

The heading information for the new phase is read first. The first column of the heading should contain a 1. A field of 48 characters is allowed for the heading information.

After the heading information, phase change inputs are read. The format for the phase change inputs is exactly the same as that of the main program input with one exception. The exception is that for the relative decimal location information of Field one, the symbolic location DLPN is defined as relative location one. If a negative location or a value greater than 30 is input, the program will halt and the A register can be corrected.

Following the last phase input data, a 0 value with END in Field three must be input. After the END input is read, control is transferred back to the Driver routine and the new phase data are processed.

Table 4-IX is a sample list of Driver phase inputs.

Table 4-IX. Example of Driver Phase Input

			Fail Sim. Test 1.1
1	15	DL	0.5100000E-00
3	-4	DL	0.4000000E-01
4	0	H1N	0.9999999E-01
25	0	WNVX	0.9999999E-01
26	0	WNVY	0.2000000E 00
27	0	WNVZ	0.4000000E 00
0	0	END	0.0000000E 00

4.2.6.5 Output Operation

4.2.6.5.1 Real-Time Display Routine. Sense Switches 3 and 4 are used in selecting a set of parameters to be output to the Real-Time Display. Both navigation and alignment routines in the real-time mode or simulation mode display a certain set of parameters. The list of parameeters displayed with corresponding switch settings is presented in Table 4-X. The Real-Time Display routine is entered once per major cycle. The sense switch may be changed during a run to change the set of parameters to be displayed.

Table 4-X. Real-Time Display Format – Driver Phase

Sense Switch Setting		ID Code	Align Flag	Word 1 (Channel 15)	Word 2 (Channel 16)	Word 3 (Channel 17)	Format
3	4						
OFF	OFF	0	-	Time (sec)	FSA	FSG	XXXXXX.
OFF	ON	1	0	δRe (ft)	δRn (ft)	δALT (ft)	XXXXXX.
ON	OFF	2	0	δVv (ft/sec)	δVe (ft/sec)	δVn (ft/sec)	XX.XXXX
ON	ON	3	0	θ_V (arc sec)	θ_E (arc sec)	θ_N (arc sec)	XXXX.XX
OFF	ON	4	1	$\hat{A}$ (1, 1)	$\hat{A}$ (2, 1)	$\hat{A}$ (3, 1)	X.XXXXX
ON	OFF	5	1	$\hat{A}$ (1, 2)	$\hat{A}$ (2, 2)	$\hat{A}$ (3, 2)	X.XXXXX
ON	ON	6	1	$\hat{A}$ (1, 3)	$\hat{A}$ (2, 3)	$\hat{A}$ (3, 3)	X.XXXXX

4.2.6.5.2 <u>Magnetic Tape Output.</u> In the real-time mode of operation, a limited number of output words may be stored on a magnetic tape per major cycle. The selection of the parameter words is performed as described in Paragraphs 4.2.6.1 and 4.2.6.2. The number of major cycle output parameters is limited to be less than 60. The maximum number of output words that may be specified during a real-time operation is 80, the first 20 of which are minor cycle outputs.

The magnetic tape output operation during the real-time mode is performed by storing the values of N selected parameters ($N \leq 20$) at the end of each minor cycle computation. During the 12th to 25th minor cycle time, these stored parameters are output to the magnetic tape at the rate of not more than 2N words per minor cycle in binary format. For details of this output operation and tape output format, see Appendix C.

During the real-time mode of operation, no online change of the tape output is allowed.

4.3 SENSE SWITCH 6 OPTIONS

4.3.1 In Simulation (Driver) Mode

During a simulation mode of operation, the Sense Switch 6 may be set to stop the run and perform some additional input/output operations. The operator may select any of the following options:

a. Output up to six parameters on the typewriter

b. Input additional data into memory through the typewriter

c. Change input/output devices

d. Change output frequency

e. Write an end-of-file.

After any of the above options are selected and performed, the control can be transferred back to the program and the run will be resumed.

Detailed procedures to be followed for Sense Switch 6 options are described below.

Sense Switch 6 may be set any time during a run. The program checks the setting of the switch at the end of the minor cycle, after the

requested minor cycle output is completed. If Sense Switch 6 is set at this time, the following message is printed on the typewriter.

SELECT LIST, DATA, OR END

The operators, at this time, have a choice of one of the following inputs through the typewriter:

a. Hit the carriage return

b. Type *LIST (*means hit the space bar)

c. Type *DATA

d. Type *EOF

e. Type *TDMP (or *LDMP).

The explanation for each of these inputs is described next:

a. When the carriage return is hit, the typewriter will type out the following message:

   SELECT IN OUT UNIT AND PRINT FREQ

   At this time, new input/output devices or print frequencies can be selected with the format described in Paragraph 4.2.6.1. After the carriage return is hit, the message

   NEW OUTPUT LIST OR OLD LIST

   will be typed. The control to the driver program is accomplished by typing

   *END

   Sense Switch 6 should be returned to its off position before END is typed.

b. To list up to six parameters, type the word LIST and hit the carriage return. The RDWT S/R types the key word LIST and waits for a set of parameters to be input with the following format:

   *MM*NNNN*PPP*0000*RR----R

Field One MM (Columns 2-3)

This field has eight defined input values, 00 through 07. 00 is typed as the last entry to terminate the input sequence. In this case, the rest of the field should not be typed. The control will return to the driver after the carriage return is hit.

When 01 is typed in for the Field one, only Fields two and three are read in and they are interpreted as follows:

Field Two NNNN (Columns 5-8)

The frequency at which the specified six (or fewer) variables are to be typed. A value of 0001 will cause the variable to be typed after every minor cycle.

Field Three PPP (Columns 10-12)

The number of times the variables are to be listed during the run.

When the values 02 through 07 are typed in for the Field one input, the full format should be input to specify up to six parameters to be output. In this case the Field one values specifies the index for each of the set of parameters. Any one of the previously specified parameters may be changed without retyping the whole set of input by the use of this index number.

For this case, the rest of the fields are interpreted as follows:

Field Two NNNN (Columns 5-8)

This field specifies the decimal values of the relative location of the variable to be listed. Symbolic location AZHT is defined as having a relative location of 0001.

Field Three PPP (Columns 10-12)

This field specifies the binary scaling of the value to be listed.

Field Four 0000 (Columns 14-17)

This field specifies the name of the variable to be listed.

Field Five   RR---R (Columns 19-34)

This field specifies (in G15.7 format) the conversion factor to be used on the value to be listed. The selected variable will be multiplied by the conversion factor and typed out. If the value is not input, a conversion factor of 1.0 will be used.

The order in which the set of parameters is input is not important. As with all the sense switch options, the sense switch should be set to the off position before normal program operation is resumed.

c. To load additional data into memory after the program has already started, set the Sense Switch 6 on and type *DATA and the carriage return after the SELECT message.

   After typing out the key word DATA, the program will halt and wait for the input data to be typed in. The format for the input data is identical to that described in Paragraph 2.1.6.3. The fields have the same meaning and restrictions and AZHT is defined as relative location one.

   To terminate the data input operation type in 0 values for Fields one and two with END for the Field three (left justified). After this input is read, the control is transferred back to the main program to resume the normal program operation.

d. If magnetic tape or paper tape has been specified as the output media, an end-of-file may be written at any time by setting the Sense Switch 6 on and typing *EOF after the SELECT message.

e. If the operator wishes to get an OPW print on the typewriter when tape is being used for output, type in *TDMP and hit the carriage return after the SELECT message. A minor cycle OPW block will be typed out and then normal processing will continue. If only a major cycle OPW block was defined, then it will be printed out. No heading or line control is done and this OPW dump will not affect the normal OPW outputs. Sense Switch 6 should be returned to its off position prior to hitting the carriage return.

4.3.2 In Real-Time Mode

For a discussion of real-time mode see Paragraph 4.2.3.2.

4.4 DATA PREPARATION

Most of the nominal input data are stored in the DDP 124 computer when the RS object program is initially loaded. A very small amount of additional data is required to make the runs.

In Appendix B, input/output variables are listed for each mode of operation and are further divided into various categories. On the list of inputs, the values which are stored in the computer after the initial loading are listed under the column heading Nominal Value. The maximum value that may be input for each of the input variables is determined from the value N listed under the column Scale. The maximum value is $2^N - 2^{N-23}$, or approximately 2^N. If the input value exceeds the maximum value, the maximum value is stored for that parameter.

4.4.1 Program Flags, Counters, and Time Variables

The nominal values for the above parameters are set for running the RS program in the simulation mode with a 40-msec minor cycle time, 25-minor cycles to a major cycle, and no sensor failure simulated.

The parameter NNCP and DLTI should not be changed since the RS program is designed to operate with a 40-msec minor cycle time and 25-minor cycles to a major cycle.

For a calibration run, the calibration flag, CALF, must be set to 1. In this case, the rest of the inputs listed in Table 4-XI will be disregarded by the program.

Table 4-XII defines the settings of the DRVE and ALGN flags for the corresponding modes of operations. For all of these modes of operations, the flag CALF must be set to 0. The failure simulation flags, FS, GFS, and AFS, may be set for any of the modes of operations to introduce sensor errors. Input data preparation for the failure simulation routine is described in Paragraph 2.2.7 of Volume II, Reference 3.

Table 4-XI. Flags, Counters, and Time Variables

Equation Symbol	Program Symbol	Relative Location	Scaling	Nominal Value	Units	Definition
DRIVE	DRVE	64	23	1	-	= 1 for driver = 0 for real time = -1 for tape input
ALIGN	ALGN	239	23	0	-	= 0 Navigation mode = 1 Alignment mode
CALIB	CALF	249	23	0	-	= 0 no calibration = 1 Calibration mode
F_s	FSS	10	23	0	-	= 1 to simulate sensor errors = 0 otherwise
GFS	GFS	12	23	0	-	= 1 to simulate gyro errors = 0 otherwise
AGS	AFS	11	23	0	-	= 1 to simulate accelerometer errors = 0 otherwise
N_N	NNCP	3	10	25	-	Number of minor cycles in a major cycle
Δt_I	DLTI	2	-4	.04	sec	Initializing delta t

Table 4-XII. DRVE and ALGN Flags (Navigation and Alignment Modes)

DRVE	ALGN	Mode of Operation
1	0	Navigation with driver
-1	0	Navigation with input tape
0	0	Navigation with sensor inputs
1	1	Alignment with driver
-1	1	Alignment with input tape
0	1	Alignment with sensor inputs.

5. CALIBRATION TEST PHASE

5.1 GENERAL

The objectives and rationale for the calibration tests are given in References 2 and 5.

Derivation of the calibration equations are given in Appendix C Volume I, Reference 3. Equation flow charts are given in Volume II, Subsection 3.3.

5.2 TEST REQUIREMENTS

The specific requirements of this test phase to satisfy the test objectives are:

a. Validate compatibility of the calibration program, the BB DDH, and the test equipment interfaces.

b. Validate the sign conventions, term by term, in the measurement and computation of all compensation parameters.

c. Establish the accuracy of the calibration systems by 1) error analysis and 2) empirical confirmation.

d. Determine compensation parameter coefficients for main program. Verify consistency with prior values for the same instruments.

e. Obtain repeated and redundant data and analyze for:

   Parameter repeatability

   Measurement accuracy

   OA axis g sensitive drift

   Position sensitivity

   Hysteresis

   Channel intercoupling

   Temperature sensitivities

   Other anomalies

f. Determine the required recalibration interval for the balance of the test program.

g. Develop operator skill in performing calibrations (a significant factor in inertial equipment testing).

5.3 CALIBRATION TEST SERIES

It is anticipated that three weeks will be required to obtain sufficient data to satisfy all of the test requirements listed in Subsection 5.2. Testing will consist of repetitions of all or part of the calibration sequence described below, and special investigations as required.

In the initial stages, single position data (pulse counts) will be read out frequently to confirm the calculations and, particularly, to verify that the correct polarity is assigned to bias and g-sensitive drift terms.

The test duration should be kept flexible and should last until the requirements are satisfied. Probably no less than 10 successful calibrations will be performed.

A flow diagram of the test and analysis sequence is shown in Figure 5-1.

5.4 CALIBRATION SEQUENCE

A complete sensor calibration sequence requires that the BB DDH be oriented in the nine positions shown in Figure 5-2. The nominal sequence for the RSP is:

	Position
1. Rate test position	1
2. Remount fixture	
3. Rate test	2
4. Remount DDH	
5. Rate test	3
6. Compute rate test results	
7. Static test	4
8. Static test	5
9. Static test	6
10. Static test	7
11. Remount DDH	
12. Static test	8
13. Static test	9
14. Compute static test results	

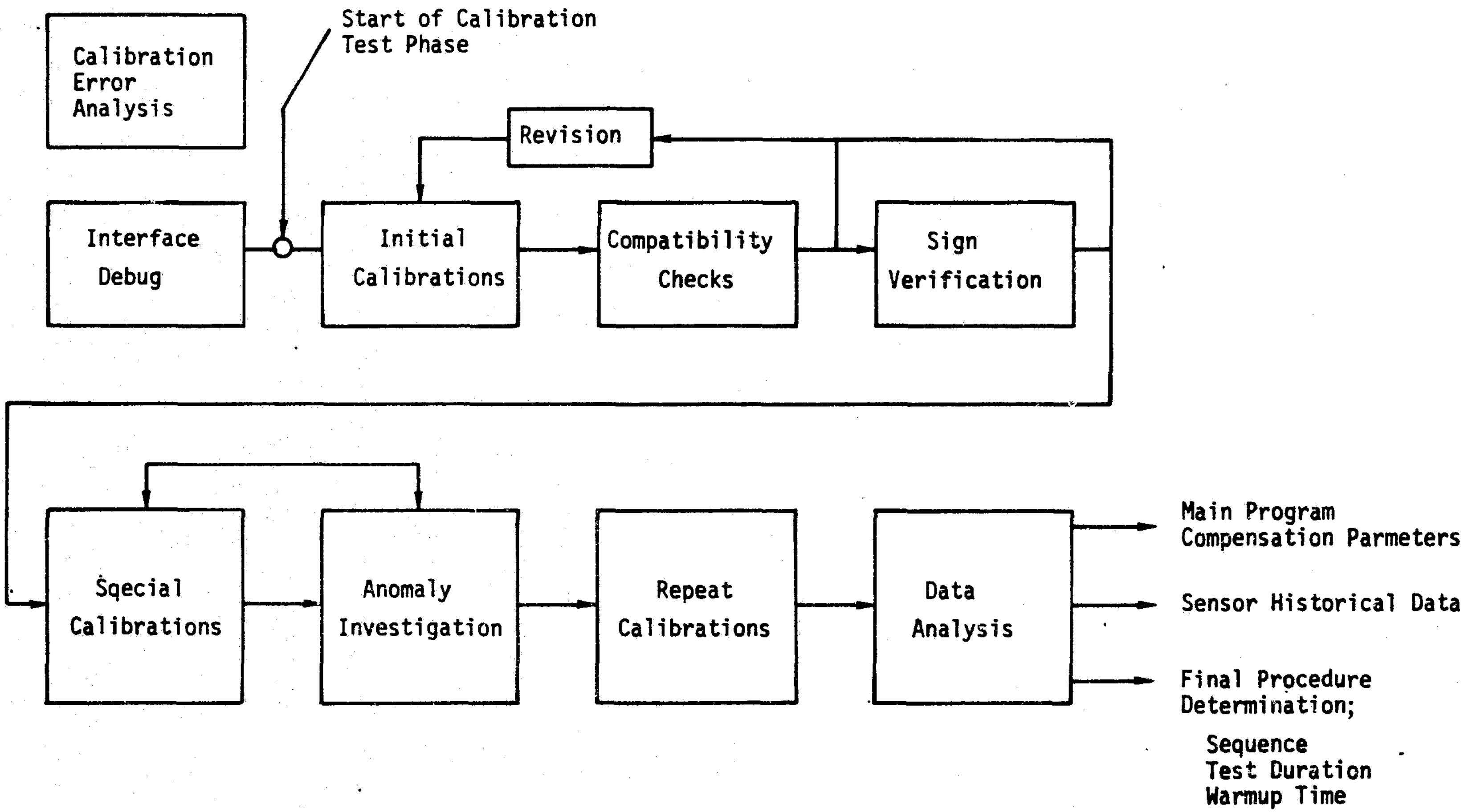

Figure 5-1. Calibration Test Flow Chart

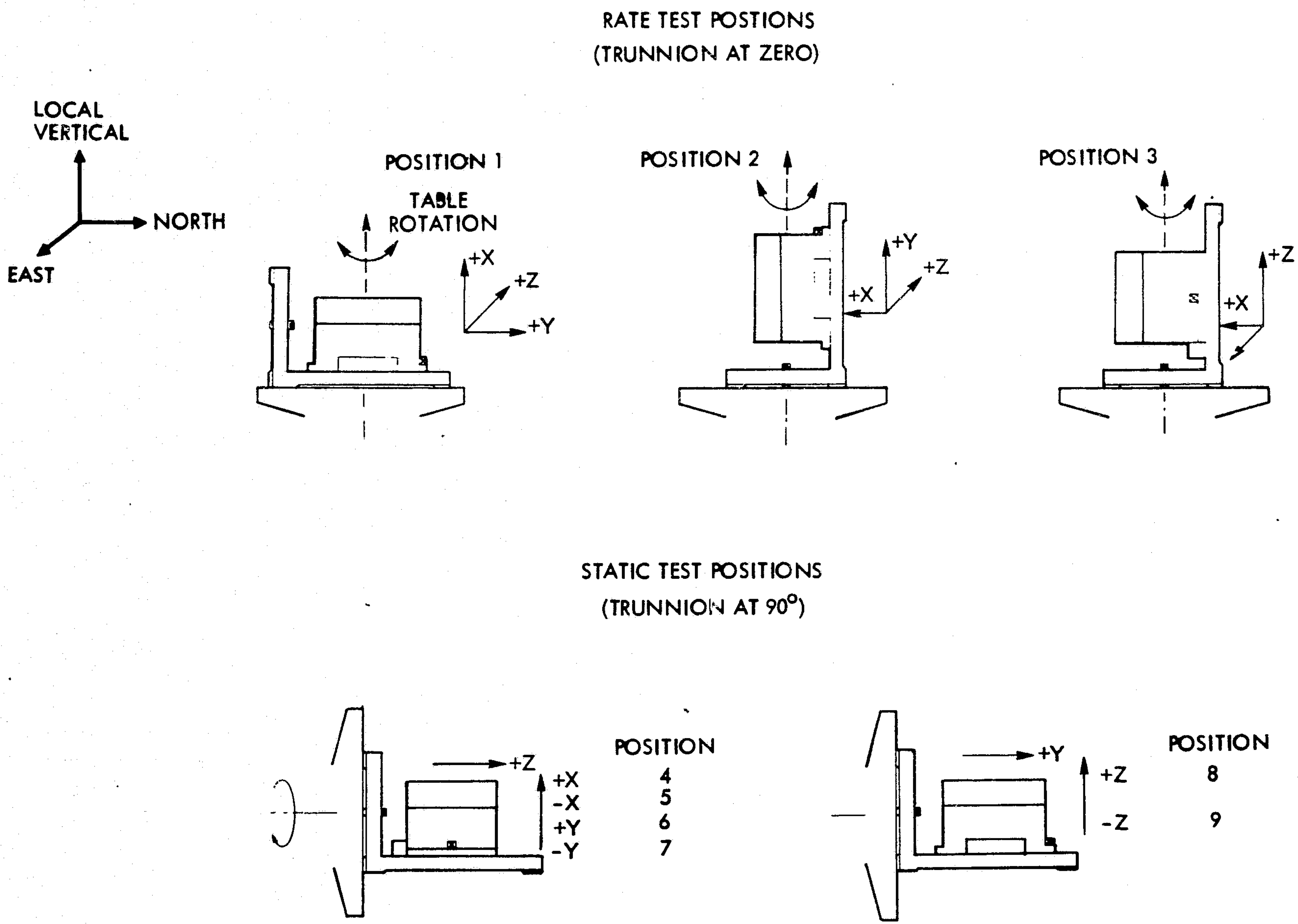

Figure 5-2. BB DDH Calibration Test Positions

The static tests and computation can be performed separately by inputting (from paper tape) previously measured gyro scale factors and direction cosines.

A modified sequence requiring one less remounting is given in Paragraph 5. 5. 5, but the sequence above should be used for initial system verification as the operating procedures are more straightforward.

5. 5 CALIBRATION PROCEDURES

This subsection defines the operations to be performed to measure the BB DDH sensor parameters. The procedures and requirements for alignment of the GOERZ table and mounting of the test article on the GOERZ table are given in Appendix A.

There is some repetition of information in Section 4 to make this section nearly self-contained.

5. 5. 1 Pretest Preparation and Cautions

5. 5. 1. 1 Operate BB DDH with Heaters for 1-hr Minimum Before Commencing Calibration

5. 5. 1. 2 Verify Rate Table Alignment as Specified in Appendix A

5. 5. 1. 3 Set Up Laboratory Test Equipment to Monitor Appropriate BB DDH Operating Voltages

5. 5. 1. 4 Cautions

Mechanical and thermal shock must be avoided during the calibration process. Gyros are to be spun down before remounting. A calibration sequence should be continuous, uninterrupted, and the time to perform each step should be standardized.

5. 5. 2 Program Loading

Perform the steps defined in Paragraph 4. 2. 1.

5. 5. 3 Rate Table Tests

1. Position of BB DDH with the assembly X axis up (position 1 of Figure 5-2) and the SAR gimbals to the reference positions specified in Table 5-I.

Table 5-I. SAR Gimbal Alignment in Calibration

SAR	DDH Reference Axis
X1, X2	Output axis along +Z
Y1, Y2	Spin axis along +X
Z1, Z2	Spin axis along -Y

2. Complete the following computer initialization operations as in Paragraphs 4.1.2 and 4.2.3.

   a. Depress the O&P pushbutton and key in starting address 00100 on the pushbuttons

   b. Set the sense switches for the rate table test as shown in Table 5-II. Depress the START button of the DDP-124 computer.

Table 5-II. Sense Switch Positions (Calibration Tests)

Test/Computation Options	Sense Switch		
	SS_1	SS_2	SS_3
Rate table test	1	X	0
Static table test	0	1	0
Rate table test computations only	1	X	1
Static table test computations only	0	1	1

(1) Indicates switch is up

(0) Indicates switch is down

(X) Indicates switch may be in either position

c. Select input/output devices and print frequency.

- Select Input = Paper Tape, Output = Typewriter, Major Cycle Print Frequency = Every Cycle (0001) using the formula defined in Paragraph 4. 2. 6. 1.

- Input the output word list specified in Table 5-III (see Paragraph 4. 2. 6. 2).

- Input the main program data specified in Table 5-IV (see Paragraph 4. 2. 6. 3).

  (After the read-in of the main program input is complete, the program proceeds to the program tag location CLB2 (see Figure 3-7, Volume II, Reference 3).

3. Set the sense switches for X axis up, positive rotation, as shown in Table 5-IV.

4. Introduce a positive (CCW viewed from above) constant rate of 10 deg/sec about the GOERZ table rotary (vertical) axis.

5. Depress the START button of the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation (one revolution).

   Note: Program will halt after accumulating table pulses equivalent to 360 deg. For consistency, START should occur with the BB DDH axes at approximately the same azimuth for every rate calibration run.

<u>End of X Axis Positive Phase</u>

6. Rezero the SAR gimbals as in step 1 (Paragraph 5. 5. 3. 1). Set the sense switches for X axis UP, negative rotation, as shown in Table 5-IV.

7. Introduce a negative constant rate of 10 deg/sec about the X axis.

8. Depress the START button on the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation.

   Note: Program will halt after accumulating table pulses equivalent to 360 deg.

Table 5-III. Output Data for Rate Table Test

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
K_i	GSFK	477-483	3	arc sec/pulse	Gyro scale factors (6)
C'_{Iix}	CPAX	522-527	0	---	Gyro direction cosine, 1st column
C'_{Iiy}	CPAY	528-533	0	---	Gyro direction cosine, 2nd column
C'_{Iiz}	CPAZ	534-539	0	---	Gyro direction cosine, 3rd column
$(C)_g$	CCMX	878-967	0	---	C matrix (15 x 6)
n_{AXP}	NAXP	405-410	23	Counts	Raw gyro counts, X positive
n_{AXN}	NAXN	411-416	23	Counts	Raw gyro counts, X negative
n_{AYP}	NAYP	417-422	23	Counts	Raw gyro counts, Y positive
n_{AYN}	NAYN	423-428	23	Counts	Raw gyro counts, Y negative
n_{AZP}	NAZP	429-434	23	Counts	Raw gyro counts, Z positive
n_{AZN}	NAZN	435-440	23	Counts	Raw gyro counts, Z negative
θ_x	THTX	390 21	1.296E6	arc sec	Total rate table angle about the X, Y and Z axes, respectively (see note)
θ_y	THTY	391 21	1.296E6	arc sec	
θ_z	THTZ	392 21	1.296E6	arc sec	

Note: θ_x, θ_y and θ_z should equal an integral number of revolutions.

Table 5-IV. Rate Table Test Switch Assignment

Table Orientation	Table Rotation	Sense Switches					
		SS_1	SS_2	SS_3	SS_4	SS_5	SS_6
X axis Up	Positive	1	X	X	X	X	X
	Negative	0	1	X	X	X	X
Y axis Up	Positive	0	0	1	X	X	X
	Negative	0	0	0	1	X	X
Z axis Up	Positive	0	0	0	0	1	X
	Negative	0	0	0	0	0	1

(1) Indicates switch is up

(0) Indicates switch is down

(X) Indicates switch may be in either position

<u>End of X Axis Negative Phase</u>

9. Turn the BB-DDH spin power off. Remount the test mounting fixture to position the BB DDH position 2 of Figure 5-2. Turn on, allow 1-hr warmup.

10. Set the sense switches for Y axis up, positive rotation, as shown in Table 5-IV.

11. Zero the SAR gimbals. Introduce a positive constant rate of 10 deg/sec about the Y axis.

12. Depress the START button on the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation.

<u>End of Y Axis Positive Phase</u>

13. Set the sense switches for Y axis up, negative rotation, as shown in Table 5-IV.

14. Zero the SAR gimbals. Introduce a negative constant rate of 10 deg/sec about the Y axis

15. Depress the START button of the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation.

Note: Program will halt after accumulating table pulses equivalent to 360 deg.

<u>End of Y Axis Negative Phase</u>

16. Turn BB DDH spin power off. Remount the BB DDH to position 3 of Figure 5-2.

17. Turn power on and allow 1 hr for warmup. Set the sense switches for Z axis up, positive rotation, as shown in Table 5-II.

18. Zero the SAR gimbals. Introduce a positive constant rate of 10 deg/sec about the Z axis.

19. Depress the START button on the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation.

Note: Program will halt after accumulating table pulses equivalent to 360 deg.

<u>End of Z Axis Positive Phase</u>

20. Set the sense switches for Z axis up, negative rotation, as shown in Table 5-IV.

21. Introduce a negative constant rate of 10 deg/sec about the Z axis.

22. Depress the START button on the DDP-124 after a steady rate has been achieved and accumulate pulses for 360 deg of table rotation.

Note: After detecting all phases for the rate table test are completed, the program will proceed directly to next step without a halt.

23. The program performs the calibration computations and prints the output previously specified in step 2. Examine the printout for reasonability. The gyro scale factors should always read 4.9439 ± (TBD).

24. Depress the START button on the DDP-124 to store these constants in the main program. The program will halt after this operation is completed.

End of Rate Table Tests and Computations

5.5.4 Static Table Tests

1. Orient the GOERZ table to position 4 of Figure 5-2. Spin power need not be shut off if trunnion rate does not exceed one radian/sec. Zero the SAR gimbals.

2. Complete the following computer operations:

   - Depress the O&P pushbutton and key in starting address 00100 on the pushbutton-indicators.

   - Set the sense switches for the static table test as shown in Table 5-II. Depress the START button of the DDP-124 computer.

   - Select input/output devices and print frequency (see Paragraph 4.2.6.1).

   - Input the output word list specified in Table 5-V.

   - Load the input data specified in Table 5-VI.

3. Set the sense switches for "X axis up" as shown in Table 5-VII.

4. Depress the START button on the DDP-124 and accumulate sensor pulses for 240 sec.

   Note: The program will halt at the end of the sampling period.

End of X Axis Up

5. Orient the BB DDH to position 5, Figure 5-2. Do not exceed 1 rad/sec rotation rate.

6. Set the sense switches for "X axis down" as shown in Table 5-VII.

7. Repeat step 4 of this section.

End of X Axis Down

8. Orient the BB DDH to position 6, Figure 5-2.

Table 5-V. Output Data for Static Table Test

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
k_i	ASFK	631-636	-4	ft/sec/pulse	Accelerometer scale factor (3)
b_i	LBA	691-696	1	ft/sec^2	Average biases of accelerometer (3)
b_{ix}	LBAX	673-678	1	ft/sec^2	Accelerometer biases when X, Y, or Z axis, respectively, is vertical
b_{iy}	LBAY	679-684	1	ft/sec^2	Accelerometer biases when X, Y, or Z axis, respectively, is vertical
b_{iz}	LBAZ	685-690	1	ft/sec^2	Accelerometer biases when X, Y, or Z axis, respectively, is vertical
C'_{Aix}	KPAX	715-720	0	---	Accelerometer direction cosine, 1st column
C'_{Aiy}	KPAY	721-726	0	---	Accelerometer direction cosine, 2nd column
C'_{Aiz}	KPAZ	727-732	0	---	Accelerometer direction cosine, 3rd column
B_i	CBA	733-738	6	arc sec/sec	Gyro biases (6)
M_{si}	MSA	739-744	6	arc sec/sec/g	Gyro spin axis mass unbalance
M_{Ii}	MIA	745-750	6	arc sec/sec/g	Gyro input axis mass unbalance
y_{ij}					Single position gyro biases (6)
y_{i1}	LYA1	805-810	6	arc sec/sec	Gyro bias, x up
y_{i2}	LYA2	811-816	6	arc sec/sec	Gyro bias, x down
y_{i3}	LYA3	817-822	6	arc sec/sec	Gyro bias, y up
y_{i4}	LYA4	823-828	6	arc sec/sec	Gyro bias, y down
y_{i5}	LYA5	829-834	6	arc sec/sec	Gyro bias, z up
y_{i6}	LYA6	835-840	6	arc sec/sec	Gyro bias, z down

i = A......F

j = 1......6

i	Gyro
A	Z_1
B	Z_2
C	X_2
D	X_1
E	Y_1
F	Y_2

j	Position Figure 5-2
1	4
2	5
3	6
4	7
5	8
6	9

Table 5-VI. Input Data for Static Table Test

Equation Symbol	Program Symbol	Relative Location	Scale	Nominal Value	Units	Definition
CALIB	CALF	249	23	0	--	Calibration flag should be set to non-zero value
ω_e	OMGA	548	5	15.04115	arc sec/sec	Earth rate, set to nominal value = 15.04115
λ	LMDA	549	1	0.6041388	rad	Test site latitude
θ_{YXU}	THET*	550	3	1.5708	rad	Azimuth of assembly axes (6) (see below)
θ_{YXD}		551	3	3.14159		
θ_{ZXU}		552	3	0		
θ_{ZYD}		553	3	0		
θ_{XZU}		554	3	3.14159		
θ_{XZD}		555	3	4.71239		
K_i	GSFK**	477-482	3	4.9439	arcsec/pulse	Gyro scale factors (6)
C_{Iix}	CIAX**	504-509	0	--	--	Gyro direction cosine, not corrected by GAMX, Y, Z (sensor and table reference axes misalignment angle)
C_{Iiy}	CIAY**	510-515	0	--	θ	
C_{Iiz}	CIAZ**	516-521	0	--	θ	

*Definition for each of the assembly axis azimuth is as follows:

THET	YXU	550	Azimuth of Y axis when X axis is up
	YXD	551	Azimuth of Y axis when X axis is down
	ZYU	552	Azimuth of Z axis when Y axis is up
	ZYD	553	Azimuth of Z axis when Y azis is down
	XZU	554	Azimuth of X axis when Z axis is up
	XZD	555	Azimuth of X axis when Z axis is down

**These constants need not be input if the rate table test is performed prior to the static table test.

Table 5-VII. Static Table Test Switch Assignment

Position (Figure 5-2)	Table Orientation	Sense Switches					
		SS_1	SS_2	SS_3	SS_4	SS_5	SS_6
4	X axis up	1	X	X	X	X	X
5	X axis down	0	1	X	X	X	X
6	Y axis up	0	0	1	X	X	X
7	Y axis down	0	0	0	1	X	X
8	Z axis up	0	0	0	0	1	X
9	Z axis down	0	0	0	0	0	1

9. Set the sense switches for "Y axis up" as shown in Table 5-VII.

10. Repeat step 4 of this section.

<u>End of Y Axis Up</u>

11. Orient the BB DDH to position 7.

12. Set the sense switches for "Y axis down" as shown in Table 5-VII.

13. Zero the SAR gimbals. Repeat step 4 of this section.

<u>End of Y Axis Down</u>

14. Turn the spin power off. Remount the BB DDH to position 8 (see Figure 5-2) with the Z axis up. Turn power on and allow 1 hr warmup.

15. Set the sense switches for "Z axis up" as shown in Table 5-VII.

16. Zero the SAR gimbals. Repeat step 4 of this section.

<u>End of Z Axis Up</u>

17. Orient the BB DDH with the assembly Z axis down, position 9, Figure 5-2.

18. Set the sense switches for "Z axis down" as shown in Table 5-VII.

19. Zero the SAR gimbals. Repeat step 4 of this section.

End of Z Axis Down

20. The program performs the calibration computations and prints the output specified in step 2 of this section.

21. Depress the START button on the DDP-124 to store these constants in the main program.

End of Static Tests and Computations

5.5.5 Revised Calibration Sequence

A sequence that requires one less remounting of the BB DDH is given below. After initial system verification, it may be desirable to use this procedure to reduce test time. Also, test repeatability should be better because the thermal and mechanical transients associated with remounting are reduced.

		Position (Figure 5-2)
1.	Static test	4.
2.	Static test	5
3.	Static test	6
4.	Static test	7
5.	Rate test	3
6.	Remount DDH	
7.	Rate test	2
8.	Static test	8
9.	Static test	9
10.	Remount fixture	
11.	Rate test	1
12.	Compute rate test results	
13.	Compute static test results	

This sequence requires considerable manipulation to exit from the static and rate test routines repeatedly; the calibration program logic could be changed to make this out-of-sequence operation much easier.

The program will normally stay in the rate test mode until the required six measurements have been taken, then compute the results.

The following procedure is necessary to change from static to rate tests and back, and finally to compute rate test results, then static test results.

5.5.5.1 Special Procedure for Out-of-Sequence Calibration

Without program changes, the following procedure may the followed to accomplish this out-of-sequence calibration test. In order to understand and execute this procedure, the ability to manipulate the computer with the DDP-124 control panel and familiarity with the calibration flow logic and program are required. For information on the DDP-124 Control Panel, see Honeywell Document No. 130071543, "Users Guide, DDP-124 General Purpose Computer." For information on the calibration program, see Volume II, Reference 3.

a) Position the BB DDH to the position 4 of Figure 5-2.

b) Follow step 2 of Paragraph 5.5.4 for inputting the output word list and the main program data. Both sets of the word list and data must be input in this case. (Tables 5-III, 5-IV, 5-V, and 5-VI). The sense switch should be set for the static test.

c) Follow steps 3 through 13, Section 5.5.4. After the program halts at the completion of step 13, confirm that the A register reads 000000038 (CTFG). The program counter at this time should read 00016117_8.

d) With pushbutton-indicator of the DDP-124 Control Panel, change the program counter to 00016103_8. Set the sense switches to the rate table data sampling configuration (SS_1 = 1, SS_3 = 0), and push START. The program will halt at the location 00016117_8.

e) Follow steps 16 through 22, Paragraph 5.5.3 (Rate Test). The program will halt at the location 00016117_8 with the A register showing 00000074_8.

f) Follow steps 9 through 15, Paragraph 5.5.3. The program will halt at the location 00016117_8 with the A register showing 00000060_8.

g) With the pushbutton-indicator, change the program counter, to 00016103_8. Set the sense switches to the static test data sampling configuration (SS_1 = 0, SS_2 = 1, SS_3 = 0), and push START. The program will halt with the program counter showing 00016117_8.

h) Follow steps 14 through 19, Paragraph 5.5.4. This completes the data sampling for the static test. The program will halt with the program counter showing 00016117_8. (CTFG or A register is non-zero at this time. It should be 00000074_8.)

i) With the pushbutton-indicator, change the program counter to 00016103_8. Set the sense switches to the rate table test data sampling configuration (SS_1 = 1, SS_3 = 0), and push START. The program will halt with the program counter showing 00016117_8.

j) Follow step 1 and steps 3 through 8. The program will halt at the location 00016117_8. This completes the sampling for the rate test. Now all the data necessary for the calibration computation are stored in the program.

k) With the pushbutton-indicator, change the program counter to 00016103_8. Set sense switches to the rate table test computation only configuration (SS_1 = 1, SS_3 = 1), and push START.

L) The program will perform the rate table test computations, print out the output requested by step 2 of this section, and will halt with the program counter showing 00016467_8. The outputs for the static table test will be output at this time. However, most of these outputs are meaningless.

m) If is desired to place the results of the rate table test computation into main program, push START. The program will halt at the location 00016614_8 after the completion of the operation. Otherwise, omit this step.

n) With the pushbutton-indicator, change the program counter to 00016103_8. Set the sense switches to the static table test computation only configuration (SS_1 = 0, SS_2 = 1, SS_3 = 1), and push START.

p) The program will perform the static table test computations, print out the output requested by step 2 of this section, and will halt.

q) If it is desired to place the results of the static table test computation into the main program, push START. This completes the calibration operation.

5.6 DATA COLLECTION AND PROCESSING

5.6.1 Data Sheets

A standardized calibration procedure should be developed and used frequently during the course of the test program.

A data sheet containing at a minimum the following information should be prepared and filled out for each calibration run:

- Date, time
- Laboratory temperature (if it varies more than a few degrees)
- BB DDH voltage measurements
- Time sequence

  List time of initial turn-on
  Time and position for each data collection period
  Time of turn off and on for remount
- Digital Data

  List of printouts from Tables 5-III and 5-V
  For initial runs also list raw data counts (see Table B-V)
- SAR gimbal readouts at the beginning and end of each test
- Comments.

The data sheet should contain acceptable bounds on measured parameters.

Permanent records and plots of all calibration results should be maintained for stability and trend analysis. Means and covariances shall be computed for the ensemble of calibration parameter accumulated throughout the program.

5.6.2 Nominal Alignment Matrices

The main program contains nominal values for the gyro and accelerometer direction cosine matrices and FDDC "C" matrices (15 x 6).

After the true values of these matrices have been established for the BB DDH, the main program constants for the nominal values (Section B. 4) should be revised to the measured values. This will be a one-time program change.

5.7 TEST EVALUATION

5.7.1 Data Reduction Equation Discussions

The scaling and format changes necessary to the calibration program have been defined in References 2 and 5. One additional minor change that should be performed is to set:

$$b_A = b_{AZ}$$
$$b_C = b_{CX}$$
$$b_E = b_{EX}$$

This sets each accelerometer bias compensation equal to one (the most appropriate) of the three bias estimates per channel rather than the mean of all three.

With the SAR gimbals oriented as specified in Table 5-I, the RSP data reduction equations are compatible with the BB DDH SAR configuration. Limitations are:

- SAR internal misalignments are not separately measured
- Output axis g-sensitive drift is not measured.

5.7.2 Sign Verification

The possibility of sign inversion in determinations of any of the calibration parameters must be investigated. For the initial calibration runs, the accumulated pulse counts for each sensor in each position should be printed out at the end of the run. Hand calculations should then be performed to verify the sign of bias and g-sensitive terms.

5.7.3 Calibration Error Evaluation

An error analysis should be performed estimating the total calibration errors.

Comparison with prior sensor calibrations and self-consistency of parameter measurements will be used to confirm the measurement error analysis.

5.7.4 Sensor Performance Evaluation

Since in this initial test phase the total system accuracy is limited, the only planned sensor performance evaluation will be to estimate parameter stability, repeatability, and trend (bias) values.

Determination of correlation coefficients, dynamic errors, second-order errors etc., will not be attempted unless problems develop. The initial calibration data shall be examined for evidence of: position sensitivity, hysteresis, settling characteristics, and temperature sensitivity.

The outputs of this evaluation will be:

1) Test limits for future calibrations
2) Sensor error values for navigation test error predictions
3) Compensation constants for navigation tests
4) A finalized calibration sequence and schedule.

6. ALIGNMENT TEST PHASE

6.1 GENERAL

The objectives and rationale for the laboratory alignment tests are given in Reference 5. Derivation of the alignment equations is contained in Reference 3, Volume I, Appendix A, and Reference 4, Volume II, Appendix D.

6.2 TEST REQUIREMENTS

The specific test requirements are:

a. Validate compatibility of the alignment program and the BB DDH hardware.

b. Evaluate alignment settling time with the large BB DDH sensor quantization values

c. Evaluate accuracy and settling time as a function of initial azimuth estimate error.

d. Evaluate alignment accuracy and settling time with single-axis oscillatory motion representative of stationary aircraft sway.

6.3 ALIGNMENT TEST SERIES

6.3.1 Nominal Sequence

The planned sequence of alignment tests is given in Table 6-I. This sequence shall be modified as necessary, as the test progresses, to accomplish the test requirements. Two to three weeks should be allowed for this test phase.

Gyro-bias calibration must be performed frequently during the calibration test series. The intervals will be determined by the measured stability of the bias parameters. Updating prior to alignment tests should be such that the total bias uncertainty after compensation does not exceed 0.05 deg/hr per axis.

6.3.2 One Position Bias Determination Procedure

If it is necessary to obtain the desired bias compensation accuracy, a single-position bias measurement shall be made in the alignment orientation prior to a run as specified in Paragraph 6.4.2.4.

Table 6-I. Alignment Test Series

Test Sequence	No. of Runs	Condition	Position Y Axis Azimuth	Initial Azimuth Error Estimate	Purpose
1	5-10	Static	Position 4 90 deg	0 deg	Compatibility check, accuracy, repeatability
2	4	Static	Position 4 90 deg	5 and 15 deg	Evaluate settling time versus initial azimuth estimate
3	2	Static, 4 deg/hr bias error in Z_2 Gyro with and without compensation	Position 4 90 deg	0 deg	Polarity check on alignment and compensation routines
4	2	Static	Position 7 X at 90 deg	0 deg	Evaluate effect of attitude on alignment
5	9	Dynamic 3 runs at each rate in Table 6-II about Z axis	Position 4 90 deg	0 deg	Evaluate accuracy and settling time under dynamic conditions
6	2	Dynamic, max rate in Table 6-II	Position 4 0 deg	15 deg	Evaluate worst-case settling time
7	2	Static	Position 4 0 deg	0 deg	Rerun of series 1 for stability and repeatability

6.3.3 Dynamic Test Levels

With the GOERZ table trunnion at 90 deg as in position 4, Figure 5-2, a low-frequency horizontal-axis oscillation, shall be used to simulate vehicle sway motion during alignment. The motion shall be terminated and the BB DDH returned to its starting position prior to the completion of alignment. The simulated sway motion shall be as specified in Table 6-II.

Table 6-II. Simulated Sway Motion

Run	Sway-Amplitude 0-Peak	Frequency H_z
1	1.6 deg	0.1
2	0.6 deg	0.25
3	0.3 deg	0.5

6.4 ALIGNMENT TEST PROCEDURE

6.4.1 General

The procedure given includes dynamics. For a static test, omit steps 6.4.3.g and 6.4.3.i. The nominal calibration interval, during the alignment tests, will be established in the software checkout phase.

6.4.2 Pretest Procedure

1. Operate the BB DDH and test equipment for 1 hr minimum before commencing tests
2. Verify the BB DDH test orientation using bubble levels and optics for azimuth). Nominally, position 4, Figure 5-2, alignment methods are given in Appendix A.
3. Measure and record BB DDH parameters as specified in Paragraph 6.5.1.
4. Update the gyro bias compensation values. If normal calibration procedures and stability are inadequate, total gyro bias compensation in the alignment test position shall be determined as follows:

a. Enter the calibration mode and perform the static measurement for one position only (typically position 4)

b. Compute static test results (a valid direction cosine matrix in the program is assumed) and readout the six gyro-bias values, Y_i where i = A, B, C, D, E, and F.

c. Manually enter the six Y_i values in the main program (after unit conversion), and set the twelve MI_i and MS_i values to 0.

d. In order to perform the gyro-bias update with the single-position static test, the procedure is:

1) Perform steps 5.5.2 and 5.5.4.2 for the program loading, output list input, and program data input.

2) Perform the static test for one table configuration with the corresponding sense switch setting. The program will halt with the program counter showing 00016117_8.

3) Manually change the program counter to 00016103_8. Set sense switches to static test, computation only (SS_1 = 0, SS_2 = 1, SS_3 = 1) and push START.

4) The program proceeds with the static test computation with the available data and prints out the results. Some of the results printed out at this time have no significance because of insufficient data sampling. Do not push START button at this time which would store <u>all</u> results in the main program.

5) Convert Y_{ij} (gyro bias in arc/sec) into pulses/40 msec. Compute the octal values of the gyro biases ($\hat{d}gi$) with the scale of B15 and enter into the main program through the control panel.

$$\hat{d}gi\ (\text{pulse}) = \frac{Y_{ij} \cdot KRS}{\hat{K}_{gi}} \cdot \frac{(\text{arc/sec})(\text{rad/arc sec})}{\left(\frac{\text{rad/sec}}{\text{pulse}}\right)}$$

$$KRS = 0.48481327 \times 10^{-5} (\text{rad/arc sec})$$

6.4.2.5 FDDC Logic Selection

Initial testing in the alignment and navigation modes is to be performed without instrument failures; therefore, set Sense Switch 1 ON and Sense Switch 2 OFF for the internal monitor mode (Table 4-V).

6.4.3 Real-Time Alignment Procedure

a. Load the Alignment Program by performing the operations defined in Paragraph 4.2.1

b. Complete the operations defined in Paragraph 5.5 or input the necessary calibration constants into the main program

c. Refer to Paragraph 4.2.2 and complete the following computer operations:

   1. Depress the O&P pushbutton and key in starting address 00100.

   2. Select the input/output devices and print frequency

Input	-	Tape reader or typewriter
Output	-	Magnetic tape
Frequency	-	Every minor cycle.

   3. Input the desired output words from Table 6-III. A complete list of output parameters is given in Appendix B.

   4. Input the main program input data specified in Table 6-IV if different from the nominal values.

      Note: The azimuth estimate ($\hat{A}_z$) and run duration (N_6) will be changed frequently. Alignment in any test position other than position 4 (Figure 5-2) requires new values of R_L^T and $\underline{\phi}$ as listed in Table 6-V.

d. Initialize the SAR gimbal positions as shown in Table 5-I.

e. Set Sense Switches 3 and 4 to display the desired outputs specified in Table 6-VII on the real-time display.

f. Depress the START button on the DDP 124 to align for N_6 sec.

Table 6-III. Alignment Output Data

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
		Major Cycle Data			
$\underline{\theta}'$	TTAV	832-834	3	rad	Attitude error vector (VEN)
$\hat{A}$	AHTX	716-724	1		Estimated rotation matrix from inertial to body-fixed coordinates
		Minor Cycle Data			
n_3	NN3	140	23		Align minor cycle counter
$P'ai$	APUL	841-846	15	pulses	Accelerometer outputs (6x1)
$P'gi$	GPUL	847-852	15	pulses	Gyro outputs (6x1)

Table 6-IV. Run-Dependent Alignment Input Parameters

Equation Symbol	Program Symbol	Relative Location	Test Values (Position 4)	Definition
$\hat{\phi}D$	PHTD	238	0.604138811 rad	Initial geodetic latitude estimate
$\hat{\theta}L$	TLHT	247	4.7705299 rad	Initial geodetic longitude estimate
R_L^T	RLTX	77-85	001 010 -100	
$\underline{\phi}$				Orientation of BB DDH on table top
$\phi1$ $\phi2$ $\phi3$	PHIV PHIV+1 PHIV+2	65 66 67	0 0 0	Defined in Figure A-14, Volume I, Reference 3
$\hat{A}_2$	AZHT	1	0^*	Initial azimuth estimate
N_6	NN6	250	1800 sec	Number of seconds for alignment

*+Z axis is north at zero azimuth

Table 6-V. Alignment Matrices as a Function of Test Position

Position (Figure 5-2)	R_L^T	$\phi 1$	$\phi 2$	$\phi 3$
1	100 010 001	$\pi/2$	$\pi/2$	0
2	100 010 001	$\pi/2$	0	0
3	100 010 001	0	0	0
4	001 010 -100	0	0	0
5	001 010 -100	0	0	π
6	001 010 -100	0	0	$\pi/2$
7	001 010 -100	0	0	$-\pi/2$
8	001 010 -100	$\pi/2$	0	$-\pi/2$
9	001 010 -100	$\pi/2$	0	$\pi/2$

Table 6-VI. Main Program Flag Settings

Mode of Operation	Flag Settings		
	CALF	DRVE	ALGN
Calibration	1	X	X
Navigation with Driver	0	1	0
with Tape Input	0	-1	0
with BB DDH	0	0	0
Alignment with Driver	0	1	1
with Tape Input	0	-1	1
with BB DDH	0	0	1

X denotes flags are not checked

Table 6-VII. Real-Time Display — Align Mode

Sense Switches		ID Code	Format	Display 1 (Channel 15)	Display 2 (Channel 16)	Display 3 (Channel 17)
3	4					
Off	Off	0	XXXXXX.	Time (sec)	FSA	FSG
On	Off	2	X.XXXXX	$\hat{A}(1, 2)$	$\hat{A}(2, 2)$	$\hat{A}(3, 2)$
Off	On	1	X.XXXXX	$\hat{A}(1, 1)$	$\hat{A}(2, 1)$	$\hat{A}(3, 1)$
On	On	3	X.XXXXX	$\hat{A}(1, 3)$	$\hat{A}(2, 3)$	$\hat{A}(3, 3)$

g. Introduce the desired low frequency, low amplitude sinusoidal motion about the table rotational axis.

h. Monitor the A matrix elements and sensor failure words on the real-time display.

i. Prior to test time equal to N_6, stop the dynamic motion and reposition the ERSA to the original orientation.

j. At the end of the test, check and record the quantities displayed on the real-time display, and printout on the typewriter the $\underline{\theta}'$ vector of attitude errors (alignment errors) using the procedure of Paragraph 4.2.6.2.

6.4.4 Alignment Procedure with Magnetic Tape Input

Minor cycle data (sensor outputs) must have been recorded and converted to the format of the Tape Input routine (see Appendix C.3).

An input tape is read from the Magnetic Tape Unit 1. The operating procedure is then identical to real time above, except that in step b, flag settings (Table 6-VI) are set for alignment with tape input (DRVE = -1).

6.5 DATA COLLECTION AND PROCESSING

6.5.1 Data Sheet

A calibration data sheet should be prepared containing, at a minimum, the following data:

Date, time, run number
BB DDH position, location (lab or van)
Dynamic table input
Input mode sensor, tape, Driver,
Run duration (N_6)
BB DDH voltage measurements
$\hat{A}$ matrix readout at 5-min intervals
$\underline{\theta}'$(VEN alignment errors) at end of run
Comments

6.5.2 Taped Data

Minor cycle sensor accumulations and selected output words will be recorded on magnetic tape. To use this tape as input data (for repeatability checks with identical input data) it must be reformatted to the input tape format specified in Appendix C.3.

6.6 TEST EVALUATION

The values of interest in these tests are:

a. Alignment accuracy

b. Alignment repeatability

c. Convergence time and characteristics for static and dynamic conditions.

Alignment errors can be evaluated in several coordinate systems:

a. $\hat{A}$ matrix, body to VEN direction cosines

b. $\underline{\theta}'$ θ'_V, θ'_E, θ'_N errors in VEN coordinates

c. $\underline{\theta}$ θ_X, θ_Y, θ_Z errors in body coordinates.

$\hat{A}$ and $\underline{\theta}'$ are normal outputs. $\underline{\theta}$ can be computed by taking the dot product of the appropriate unit vectors from the computed alignment matrix, $\hat{A}$, and the known body attitude matrix A, (body to VEN direction cosines). Plots of the alignment errors, $\underline{\theta}'$, should be made for evaluating convergence characteristics. The required alignment interval for the van tests will be established.

7. NAVIGATION TEST PHASE

7.1 GENERAL

The rationale for these tests is discussed in References 2 and 5. Derivation of the Navigation Equations is given in Reference 3, Volume I, Appendix A, and Reference 4, Volume II, Appendix C.

7.2 TEST REQUIREMENTS

The specific test requirements are:

a. Validate hardware/software compatibility and compensation adequacy

b. Evaluate navigation accuracy for static and dynamic tests, compare with expected values

c. Establish baseline data for FDDC tests.

7.3 NAVIGATION TEST SERIES

7.3.1 General Sequence

The planned sequence of navigation tests in Table 7-I shall be modified as required to accomplish the test objectives. In particular, the number and duration of navigation runs should be adjusted to suit the actual performance obtained.

7.3.2 Alignment Method and Frequency

Self-alignment will normally be performed. External alignment is automatic if the self-align routine is bypassed. The direction cosine matrix will initialize to the coordinates specified by the test table inputs in Table 7-III.

To conserve time where repeated navigation runs are to be made with self-alignment, and if it is determined that alignment results are repeatable, the alignment A matrix can be input manually (paper tape) and alignment bypassed after the first run.

7.3.3 Bias Update

The required frequency of calibration and compensation update will be determined by the stability performance of the BB DDH.

Table 7-I. Navigation Test Series

Series	No. of Runs	Condition	Position	Duration	Align Method	Purpose
1	2	Static	1	20 min	Self	Compatibility, shakedown
2	3	Static	1	90 min	Self	Repeatability check, baseline data for rotational test
3	2	Static	1	90 min	External	Evaluate self versus external align
4	2	Rotational	1, after 1 min rotate at 10 deg/sec 90 deg about vertical axis (y east) second run rotate 180 deg	90 min	Self	Evaluate navigation errors in nonstatic condition
5	3	Static	4	90 min	External	Baseline data for vibratory tests
6	2	Vibratory 1-deg/sec peak at 5Hz, sine vibration about Z axis (1)	4	20 or 90 min as required	External	Evaluate vibration induced errors in navigation

(1) or maximum frequency of GOERZ table at 1-deg/sec peak

A complete calibration should be performed weekly. The horizontal gyro-bias update is the most critical parameter to navigation accuracy. The one-position bias determination described in Paragraph 6.4.2.4 can be used once or twice daily, or as required to keep the uncertainty in total (compensated) gyro bias below 0.05 deg/hr per gyro.

7.4 NAVIGATION TEST PROCEDURE

7.4.1 General

The general procedure given includes dynamics. For static tests, delete the inappropriate steps. For tests where the BB DDN is rotated, the rotation will occur within the first few minutes of the run.

7.4.2 Pretest Procedure

a. Operate the BB DDH and test equipment for 1 hr before commencing tests.

b. Align the BB DDN to the specified test position using the bubble levels and optics, as described in Appendix A.

c. Set Sense Switches 1 ON and 2 OFF to prevent failure indications by the output comparison mode.

7.4.3 Real-Time Test Procedure (Without Failures)

a. Load the Navigation program by performing the operations defined in Paragraph 4.2.1.

b. Complete the calibration and alignment operations defined in Subsections 6.4 and 5.5 or Paragraph 6.2.4.4, or input the required calibration and alignment constants into the main program.

c. End of alignment: Refer to Paragraph 4.2.2 and complete the following computer operations:

   1. Depress the O&P pushbutton and key in starting address 00100.

   2. Select the input/output devices and print frequency.

      Input - Tape reader or typewriter

      Output - Magnetic tape

      Frequency - Every minor cycle

   3. Input the desired output words from Table 7-II.

Table 7-II. Navigation Outputs

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
Major Cycle Data					
t_N	TNCP	682	15	sec	Navigation time
$\hat{A}_{LT}$	ALTH	7	25	ft	Estimated altitude
$\hat{\theta}_L$	TLHT	247	3	rad	Estimated longitude
$\hat{\phi}_D$	PHTD	238	3	rad	Estimated geodetic latitude
$\hat{\underline{V}}_E$	VEHT	793-795	13	ft/sec	Estimated velocity vector relative to earth in estimated geodetic local level coordinate
$\hat{A}$	AHTX	716-724	1	--	Estimated direction cosine matrix (3x3)
$\underline{\theta}$	THTV	803-805	-2	rad	Attitude error vector about the body axes
$\underline{\theta}'$	THTP	806-808	-2	rad	Attitude error vector about the true local level coordinate axes
$\delta\phi_D$	DLPD	810	3	rad	Latitude error
$\delta\theta_L$	DLTL	811	3	rad	Longitude error
δ_{ALT}	DLAL	812	25	ft	Altitude error
$\delta\underline{V}$	DLTV	813-815	13	ft/sec	The error in $\hat{\underline{V}}_E$
$\delta\gamma'_E$	DREP	Real-time display	23	ft	Estimated position error in east direction
$\delta\gamma'_N$	DRNP	Real-time display	23	ft	Estimated position error in north direction
Minor Cycle Data					
$p'a_i$	APUL	841-846	15	pulses	Accelerometer output pulses (6x1)
$p'g_i$	GPUL	847-852	15	pulses	Gyro output pulses (6x1)

4. Input the main program input data specified in Table 7-III.

   Note: The stop time (STPT) and the attitude-dependent parameters R_L^T and ϕ will vary from run to run. R_L^T and ϕ versus test position are given in Table 6-V. For rotational tests, input the values of R_L^T and ϕ corresponding to the final test position.

5. Input the flag settings for Navigation with BB DDH as shown in Table 6-VI.

d. Set Sense Switches 1 and 2 for internal monitor-mode only as shown in Table 4-V.

e. Set Sense Switches 3 and 4 to display the desired quantities (refer to Table 7-IV for settings).

f. Initialize the SAR gimbal positions as shown in Table 5-I.

g. Depress the START button on the DDP 124 to navigate for a period of time specified by STPT.

h. For rotational tests, approximately one minute after navigation starts to perform the required rotation, precisely aligning the BB DDH azimuth, at the new position.

i. For vibrational navigation runs, introduce the sinusoidal motion after navigation commences. Stop the vibration and return to the initial attitude before terminating the run.

7.4.4 Navigation Procedure with Magnetic Tape Input

7.4.4.1 Lab Tape Format

Recordings of minor cycle (40-msec summations) sensor outputs will be made in the lab, and converted to the input tape format (Appendix C.3). Input flag settings are made for navigation with tape input (Table 6-VI). First, load the input tape on Unit 1, then proceed as described in Paragraphs 4.2.1 and 4.2.2.

7.4.4.2 Van Tape Format

Proceed as in real-time procedure, above. Analog recording will be used as shown in Figure 9-1. Tape operation is discussed in Section 9.

Table 7-III. Navigation Test Input Data

Equation Symbol	Program Symbol	Relative Location	Value for Test Position 1	Definition
ϕ_D	PHID	240	0.604138811 rad	Geodetic latitude
θL	THTL	243	4.7705299 rad	Geodetic longitude
R_L^{T*}	RLTX	77-85	100	Rotation matrix
			010	(Trunnion)
			001	
$\underline{\phi}^*$	PHIV	65-67		Orientation of BB DDH on table top
$\phi 1$	PHIV	65	$\pi/2$	
$\phi 2$	PHIV+	66	$\pi/2$	
$\phi 3$	PHIV+2	67	0	
αr	AR	237	-0.03124B-5	
αv	AV	236	0	
$\hat{\phi} D$	PHTD	238	0.604138811 rad	Initial estimate of geodetic latitude
$\hat{\theta} L$	TLHT	247	4.7705299 rad	Initial estimate of geodetic longitude

*Values for test position 1. See Table 6-V for values for other test positions.

7.5 DATA COLLECTION AND PROCESSING

7.5.1 Data Sheet

A data sheet should be prepared that includes the following information:

a. Date, time, run

b. BB DDH position, location

c. Dynamic inputs

d. Alignment method and results

e. Calibration results

f. Run duration

g. Initial gimbal position readouts

h. Final gimbal position

i. Dynamic inputs

j. Table angle data

k. VEN, velocity, position, and attitude errors at 5-minute intervals

l. For van tests
   1. Route description,
   2. Checkpoint, location versus time
   3. Tape change data
   4. Gimbal null data.

7.5.2 Taped Data

Minor cycle sensor accumulations and selected output words will be recorded on magnetic tape. To use this tape as input data (for repeatability checks with identical input data) it must be reformatted to the input tape format specified in Appendix C.3.

7.6 TEST EVALUATION

The principle object of this analysis will be to compare navigation accuracy to expected results and to resolve anomalies.

After typical sensor stability data are established from the calibration tests, and alignment accuracy from the alignment test phase, realistic estimates of expected navigation errors should be made, using the general method of Appendix A to the General Test Plan, Reference 5.

Isolation and identification of major error sources will be attempted by:

a. Plotting VEN errors (Table 7-IV) versus time.

b. Correlating the error plots with the sensor error plots of Section 3, Reference 5.

Computerized plotting routine for navigation errors is desirable to facilitate this analysis. Fine-grain error analysis will not be attempted in this prototype test program and the use of computerized error analysis programs, e.g., covariance analyses, is not anticipated.

Fixed attitude navigation tests will give the greatest (and somewhat unrealistic) accuracy because of the correlation and partial cancellation of bias and alignment errors. In multiposition tests, these correlations are lost and the errors grow.

Table 7-IV. Real-Time Display—Navigation Mode

Sense Switches 3	Sense Switches 4	ID Code	Format	Units	Display 1 (Channel 15)	Display 2 (Channel 16)	Display 3 (Channel 17)
Off	Off	0	XXXXXX.	--	time (sec)	FSA	FSG
On	Off	2	XX. XXXX	ft/sec	δV_V	δV_E	δV_N
Off	On	1	XXXXXX.	ft	$\delta r'_E$	$\delta r'_N$	δ_{ALT}
On	On	3	XXXX. XX	arc sec	θ_V'	θ_E'	θ_N'

These output displays are updated every major cycle (one second).

8. FDDC TEST PHASE

8.1 GENERAL

In this test phase, the feasibility and operational characteristics of the redundant dodecahedron configuration, using single-axis reference units, are demonstrated.

Alignment and calibration tests are repeated with various failures induced.

8.2 TEST REQUIREMENTS

The specific requirements of this test phase are:

a. Establish empirically the minimum filter constants required to prevent false alarms.

b. Evaluate failure detection time versus predicted time in the presence of noise.

c. Evaluate navigation error with sensor failures.

d. Evaluate navigation error with unfailed, but degraded sensors (below the detection threshold).

e. Evaluate multiple instrument failures.

f. Demonstrate internal monitor failure logic capability in isolating a third failure.

g. Evaluate FDDC logic susceptibility to instrument shock.

8.3 FDDC TEST SERIES

The baseline test sequence specified in Table 8-I and 8-II should be modified as required to satisfy the test requirements.

Taped sensor data will be used to make repetitive runs to evaluate changes in:

a. FDDC filter parameters

b. Sensor compensation parameters

c. Induced failures.

Table 8-I. FDDC Alignment Test Series

Test Sequence	No. of Runs	Test	Position and Y Axis Azimuth	Failure	Failure Detection Mode	Failure Detection Threshold	Purpose
1		Threshold verification	Position 4	None	Output Comparison	Variable	Lower threshold until false alarms occur to establish operating margin. Establish minimum threshold to eliminate false alarms during static operation and during a turn of 180 deg at 10 deg/sec.
2	1	Static Align	Position 4 90 deg	None	Output Comparison	0.2 deg/hr	Baseline Data
3	2	Static Align	Position 4 90 deg	Z_1 gyro failure (no output) at 30 sec	Output Comparison		Evaluate alignment accuracy degradation with one easterly gyro failed
4	2	Static Align	Position 4 90 deg	Z_1 gyro failed at 30 sec, Z_2 failed at 35 sec (no output)	Output Comparison		Evaluate accuracy with 2 gyros failed
5		Dynamic Align	Repeat sequences 2, 3 and 4 with 0.3 deg sway motion as in Paragraph 6.3.3				Evaluate dynamic alignment performance with failures

Table 8-II. FDDC Navigation Tests

Test Sequence	Test	Run Time	Position and Y Axis Azimuth	Failure			Input	FDDC		Purpose
				Failed Inst	Time sec	Type Failure		Mode	Threshold	
1	Static No failures	10 min	Position 1, Y = North	None			BB DDH		0.2 deg/hr	Baseline data
2	1 Failed	Until failed		Y1	30	2	BB DDH	Output Comparison	0.2 deg/hr	Single failure (small error)
3	Multiple failures			Y1 X1 Y2	30 +30 [1] +30 [1]	2 2 2	BB DDH BB DDH BB DDH	Output Comparison	0.2 deg/hr 0.2 deg/hr 0.2 deg/hr	Show detection of 2 failures, miss third
4		Repeat Sequence 3 with Internal Monitoring and Output Comparison								Show isolation of third failure
5	Rotation without failure	10 min	Position 1, Rotate 90°CW about vertical, Y east	None			BB DDH	Output Comparison	0.2 deg/hr	Baseline Data
6	Rotation with failure	Until failed	Fail X_1 gyro turn CCW 90 deg	X_1	Before turn	2	BB DDH	Output Comparison	0.2 deg/hr	Single failure detection with large error
			Fail Y_1 gyro Turn CW 90 deg	Y_1	Before turn	2	BB DDH	Output Comparison	0.2 deg/hr	Second failure detection
7	Static Simultaneous	10 min	Position 1, Y = North	Y_1 and Y_2	30	2	BB DDH	Output Comparison	0.2 deg/hr	Show error cancellation with dual failures
8	Soft Failure	Variable	Position 1, Y = North	Y_1		3	Tape		Varied	See Paragraph 8.4.7.2
9	Shock	-	Position 1, Y = North	-	-	-	BB DDH	Output Comparison	0.2 deg/hr	See Paragraph 8.4.7.2
10	Static	90 min	Position 1, Y = North	Select	0	4	Tape	Internal Monitor	-	Accuracy degradation with failures

1 - 30 sec after detection of previous failure

2 - No output

3 - 0 to 4 deg/hr using BB DDH torquing, or using failure simulator

4 - Discrete flag set by failure simulator

8.3.1 Threshold Verification

The first test sequence will establish the margin of the nominal failure threshold level by lowering it until false alarms occur due to normal system performance including rotation. The nominal threshold will be raised if necessary to eliminate false alarms during static operation and during a turn of 180 deg at 10 deg/sec (in the navigation mode).

In searching for the minimum threshold setting ($Kf2_g$) several time constants must be allowed for a failure to be detected. The search can be speeded up by lowering the time constant ($Kf1_g$) to 2 or 3 min. Lowering the time constant further would result in triggering the failure detection logic on the gyro quantizations noise (see Appendix C, Reference 5).

8.3.2 Alignment Test Sequence

The alignment tests will be repeated with catastrophic sensor errors, using output monitoring only. The sequence is:

Static

Repeat static alignment static test without failure as per sequence 1, Table 6-I (Y axis east). Repeat static test with Y1 gyro failed at 30 sec. Repeat with Y1 failed at 30 sec, Y2 failed 30 sec after detection of the first failure.

Dynamic

Repeat dynamic alignment test, sequence 5 of Table 6-I, with no sensor failure. Repeat dynamic alignment with one (easterly) gyro failed at 30 sec. Repeat with one gyro failed at 30 sec, a second failed 30 sec after detection of the first failure (both gyros will be those nearest the east pointing DDH axis).

8.3.3 Navigation Test Sequence

The general sequence is:

a. Baseline run, no failures

b. Catastrophic failures (1 and 2 gyros failed) output comparison only:

   1. Static navigation test
   2. Dynamic navigation test (Paragraph 7.4.7.2)

c. Catastrophic failures (1, 2, and 3 gyros failed), using internal monitoring only, static test only

d. Catastrophic failures (3 gyros failed), using both output and internal monitoring, static test only

e. Simultaneous failures

f. Soft failures, using output comparison only, varying filter parameters and sensor error level

g. Shock susceptibility.

8.3.3.1 Simultaneous Failures

The output comparison logic implemented in the RSP will be degraded and may fail if two instruments have comparable magnitude failures and the second fails before the first is detected. Tests with simultaneous failures will be made to demonstrate this.

8.3.3.2 Soft Failure Testing

This is the test phase where parametric experimentation will occur. The time required to detect a failure will be measured as a function of (1) instrument error and (2) failure threshold setting. The magnitude of navigation errors accumulated before detection of a failure will be measured. Values of instrument error and threshold setting are:

Instrument Error	0, 0.4, and 4.0 deg/hr
Threshold Setting	0.5, 1, and 2 times nominal

To provide repeatable data for evaluation of filter parameter changes, the input data shall be from tape, except for the first run.

8.3.3.3 Shock Susceptibility

The RSP failure detection logic locks up any of the 15 elements of the V vector (test signals) on the occurrence of a single check in excess of the threshold. There is some probability, therefore, of an accumulation of nonzero elements due to transients or shocks to the sensors, and ultimately switching out a sensor which had not permanently failed. A test shall be performed to examine the failure states (15 element V_{i_g} vector) with repeated shocks to the DDH, to evaluate the vulnerability of this FDDC logic scheme to noise and transients.

8.4 FDDC TEST PROCEDURES

8.4.1 General

The procedures for the align and navigation tests with failures are the same as the procedures specified above; Alignment Procedure, Subsection 6.4, and Navigation Procedure, Subsection 7.4, with the addition of steps necessary to:

1. Select the failure detection mode (sense switches)
2. Select failure simulation option when desired (FSS flag)
3. Specify FDDC input data
   - Filter threshold and time constant
   - Failure simulator inputs
4. Select appropriate output data
5. Induce the failures

8.4.2 Sense Switch Setting for Failure Detection Mode Selection

The sense switch settings to select the desired failure detection mode are given in Table 8-III.

Table 8-III. Sense Switch Setting for FDDC Routine

	Sense Switches	
	SS_1	SS_2
Output comparison only	0	1
Internal monitor only	1	0
Output comparison and internal monitoring	1	1
Program will halt	0	0

(1) - Switch in up position

(0) - Switch in down position

8.4.3 Failure Simulation Mode Flag

When the failure is to be internally generated by the Failure Simulation routine, the FSS flag is set equal to 1. See Table 4-XI.

8.4.4 Selection of Prefilter Threshold and Time Constant

Table 8-IV gives the nominal values of the filter constants (after the changes prescribed in Reference 5). The accelerometer constants are of no consequence in this test program.

The computation of Kf_{1g} and Kf_{2g} to achieve the desired threshold and time constant are performed as defined in Section C.10, Appendix C of Reference 5. The computed values will be input as normal program data input (Paragraph 8.4.8).

Table 8-IV. FDDC Filter Constants (Input Data)

Equation Symbol	Program Symbol	Relative Location	Scale	Nominal Value	Units	Definition
Kf_{1g}	KGF1	1082	0	0.99992	-	Gyro filter constant
Kf_{2g}	KGF2	1083	7	80.0	sec/rad	Gyro filter constant
Kf_{1a}	KAF1	1092	0	0.99992	-	Accelerometer filter constant
Kf_{2a}	KAF2	1092	0	0.11019886	sec^2/ft	Accelerometer filter constant

8.4.5 Selection of FSS Input Data

For details of the Failure Simulator routine and its input data, see Subsection 3.6, Volume II, Reference 3. Also, see Table 8-V.

8.4.6 Selection of Output Data

The failure state flag (FSG) will be continuously monitored on the real-time display, as shown in Table 6-VII.

Table 8-V. Data for Failure Simulation Input Routine

Program Symbol	Relative Location	Scale	Units	Definitions and Comments
DTS	268-277	15	sec	Times to input failure simulation data (10)
FSTB	278-317	-	-	Parameters to be changed (40)
FSIX	318-357	23	-	Index numbers to designate which parameters are to be changed (40)
DMFG	358-367	23	-	Discrete monitor flag for gyros (10)
DMFA	368-377	23	-	Discrete monitor flag for accelerometers (10)
FAIL	378	23	-	Binary coded fail flag

The 15-bit gyro threshold flag (FVGI) should be monitored periodically on the typewriter, as shown in Paragraph 4.2.3.2, during the shock susceptibility test or other special tests.

The information in Table 8-VI shall be included in the OPW along with the align or navigation data of Table 6-III or 7-II.

Table 8-VI. FDDC Output Data

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
Sg	FSG	915	23	-	6-bit gyro state flag
Vig	FVGI	916	23	-	15-bit gyro threshold flag
FDig	FFDG	917	23	-	18-bit gyro discrete input
Sa	FSA	918	23	-	6-bit accelerometer state flag
Via	FVAI	919	23	-	15-bit accelerometer threshold state
FDia	FFDA	920	23	-	18-bit accelerometer discrete input

8.4.7 Introduction of Failures

The sources and types of failures that will be used in this test program are discussed in the paragraphs that follow.

8.4.7.1 Internal Monitor Failures

The BB DDH has internal failure monitors for three functions for each SAR: spin motor rotation, gimbal spin monitor, and encoder error monitor. These three monitors are combined into a single failure discrete, and the six possible failure discretes are input into the 24-bit discrete input word to the IFE as shown on page 4-4 of Reference 5.

8.4.7.2 Soft Failure (External)

Gyro drift rates of 0.4 and 4.0 deg/hr can be inserted manually at the BB DDH control panel (Figure 2-1, Reference 5).

8.4.7.3 No Sensor Output

Zero output from any gyro will be caused externally by electrically disabling (or disconnecting) the channel.

8.4.7.3 Simulated Internal Monitor Failure

The Failure Simulator routine can be used to set the discrete monitor word (Paragraph 8.4.7.1) to simulate any sensor internal failures and can cause the state of the discrete word to change as many as 10 times at preselected times throughout a run.

8.4.7.4 Simulated Gyro Bias

Bias values (of any magnitude) on any of the gyros can be inserted for as many as 10 run segments. The method of specifying the sequence and magnitude of simulated failures is defined in Subsection 3.6, Volume II, of Reference 3.

8.4.8 Typical Operating Procedure

For a navigation run with combined output comparison and internal monitoring, the test steps are:

a. Perform pretest procedures as in Paragraph 7.4.2

b. Load and initialize the navigation program as per Paragraphs 4.2.1 and 4.2.2

c. Complete the calibration and alignment operations defined in Subsections 6.4 and 5.5 or Paragraph 6.4.2.4 or input the required calibration and alignment constants into the main program.

d. End of alignment. Refer to Paragraph 4.2.1 and complete the following computer operations:

   1. Depress the O&P pushbutton and key in starting address 00100.

   2. Select the input/output devices and print frequency

      Input — Tape reader or typewriter

      Output — Magnetic tape

      Frequency — Every minor cycle

   3. Input the desired output words from Tables 7-II and 8-VI.

   4. Input the main program input data specified in Tables 7-III, 8-IV, and 8-V.

      Note: Input the DMFG and DMFA data corresponding to sensors being failed (see Paragraph 8.4.5).

   5. Input STPT = 600 · seconds

   6. Set FSS flag to 1 (Table 4-XI).

   7. Input the flag settings for Navigation with BB-DDH as shown in Table 6-VI.

e. Set Sense Switches 1 and 2 for combined output comparison and internal monitoring as shown in Table 8-III.

f. Set Sense Switches 3 and 4 to display the sensor failure state words (see Table 7-IV).

g. Depress the START button on the DDP-124 to navigate for 600 sec.

h. At specified times, insert gyro bias errors at BB DDH control panel. (Third failure is to be induced by failure simulator setting discrete word).

i. Monitor the real-time display to record the time of sensor failures.

j. Record the failure times as they are detected on the real-time display.

k. If desired, the program may be interrupted for typewriter printout using the procedure of Paragraph 4.2.3.2.

8.5 DATA COLLECTION AND PROCESSING

Data collection will be as for alignment or navigation tests (Subsection 6.5 or 7.5) with the addition of the data of Table 8-VI on magnetic tape and the following parameters will be recorded on the test data sheet:

a. Time and nature of failures induced

b. Time of failure detection(s).

8.6 TEST EVALUATION

Using the methods discussed under alignment and navigation test evaluation, the test results will be analyzed in such a way as to satisfy the test requirements, which are repeated here:

a. Establish empirically the minimum filter constants required to prevent false alarms

b. Evaluate failure detection time versus predicted time in the presence of noise

c. Evaluate navigation error with sensor failures

d. Evaluate navigation error with unfailed, but degraded sensors (below the detection threshold)

e. Evaluate multiple instrument failures

f. Demonstrate internal monitor failure logic capability in isolating a third failure

g. Evaluate FDDC logic susceptibility to instrument shock.

Navigation accuracy degradation with instrument failures (sequence 10) can probably be best evaluated with taped data inducing failures at desired times with the Failure Simulator routine.

9. VAN TEST PHASE

9.1 GENERAL

The rationale and objectives of the van tests and the test configuration are described in References 2 and 5. The test purpose is to obtain recorded sensor data to be replayed in the laboratory computer for evaluation, under realistic dynamic conditions, of:

a. Self-alignment capability in the mobile van

b. Navigation capability in the mobile van

c. FDDC operation in the mobile van.

Laboratory operating procedures will not differ from those already given, except that taped sensor outputs will replace the BB DDH outputs as shown in Figure 3-2. The only procedures given here will be those connected with the following:

a. System operation and data recording in the van

b. Tape playback in the laboratory.

The van configuration and instrumentation is defined in Section 9 of Reference 5.

9.2 VAN TEST SERIES

9.2.1 Discussion

After the instrumentation and operating procedures are defined, a few taped navigations will probably suffice for all subsequent experimentation in the lab. These will range from stationary recording to a multiple turn variable speed course.

The preliminary series of runs suggested in Table 9-I should be modified with the knowledge gained in prior testing.

9.2.2 Constraints

9.2.2.1 Turning Rates

The maximum turning rate recommended is 30 deg/sec. Loss of reference from the SARs will occur at 1 rad/sec. The maximum turning rate and total angle turned are also a function of the FDDC threshold

Table 9-I. Preliminary Van Recording Runs

Run	Static Position and Duration	Align with Optics and Bubbles	Course and Maneuvers	Speed	Comments
1	X up, Z north (Position 4, Figure 5-2) 90 min	Yes	-	-	Baseline data for comparison with lab runs
2	X up, Z north (Position 4, Figure 5-2) 90 min	Yes	One 90-deg turn	-	Baseline data for comparison with lab runs
3	Position 4 for 30-min* align period at beginning and end of run	At beginning	Straight line between checkpoints, minimum turns, 90 min	Constant (20 mph)	The straight line constant speed segments will be used for verification of dynamic navigation solution
4	Position 4 for 30-min* align period at beginning and end of run	Before and after run	90-min run with approx. four 90-deg turns, return to starting point	Constant (20 mph)	Data for comparison with lab dynamic runs
5	Position 4 for 30-min* align period at beginning and end of run	Not required	Unlimited turns, 90 min	Variable 0 through 60 mph	Integrity check, no detailed analysis attempted
6	Position 4 for 30-min* align period at beginning and end of run	At beginning	6-hr run with limited turns	0 or 20 mph	For observation of long-term error propagation

*Required alignment interval will be established in the alignment test phase or simulations.

settings and sensor misalignments as will be determined experimentally in the FDDC test phase.

9.2.2.2 Vehicle Speed

The only concern with speed is the avoidance of vehicle/road resonances and severe vibration. Reference 6 suggests that 20 mph is a relatively quiet operating speed in the van so initially this will be assumed as the baseline.

9.2.2.3 Run Duration

The baseline duration shall be 90 min. Since it is possible that continuous tape recording will be limited to 15 to 30 min, the runs will be segmented, with frequent checkpoint crossings and stops for tape changes.

9.2.2.4 Failures

Failures need not be introduced in the van. All types of failures can be introduced during the playback sequence.

9.3 VAN OPERATING PROCEDURES

9.3.1 Optical Alignment

To obtain data for a gyro-bias update prior to each computer run and to verify the self-alignment function, the van will be positioned such that the BB DDH porro prism is visible to a north-referenced theodolite for azimuth alignment. Mounting adjustments will allow leveling to the self-contained bubbles.

9.3.2 Recording Quality and Tape Change Procedure

The recording setup is shown in Figure 3-2. The analog recording scheme employed is subject to data dropouts (which could destroy navigation validity) and is severely time limited. It is possible to interrupt the recording (and playback sequence) to allow for tape changes. If cruising, the vehicle should be stopped (preferably at a surveyed checkpoint) and remain motionless while the tape is changed. During playback, the navigation program will automatically be suspended when the tape data stops since the minor cycle clock is on the tape.

A special procedure to continuously monitor the recorded data for dropouts should be employed. A possible method to achieve this is to put the SAR gimbal zero pulses on tape. Prior to use in the lab, the total number of pulses from each SAR will be counted between reference (0) pulses, and should always equal 2^{18}. It will be necessary to torque all gyros past their gimbal-null position occasionally to perform this monitoring function. This should be possible without disturbing the navigation during playback if:

a. The vehicle is stationary when the gimbals are zeroed.

b. The clock is removed from the tape, which will suspend the computer operation during the gimbal rotation.

A simpler method of monitoring the integrity of the recording/playback process is to monitor and record (manually) the gimbal readout angles periodically in the van and correlate with angles measured during playback. Loss of more than a few data pulses will invalidate the tape. The time correlation in these checks must be within 1 sec.

9.3.3 Sequential Operations

For each run:

a. Allow system temperature stabilization

b. Initialize SAR gimbal angles (as in Table 5-I)

c. Align vehicle with bubbles, external optics*

d. Record sensor data for alignment interval (to be determined) avoiding all motion

e. Realign gimbals

f. Drive prescribed course, recording sensor data

g. Induce sensor failures or errors at prescribed time**

h. Stop at checkpoints and for tape changes

i. Periodically record gimbal readouts versus time for dropout detection

---

*Optional

**Failures (hard and soft) will generally be introduced at playback.

j. Record environmental and event data

k. Return to starting point and realign*

l. Record static sensor data.

9.4 RECORDED DATA

Tape-recorded data will include:

a. Six SAR outputs

b. Three accelerometer outputs

c. Time of day

d. Clock

e. Vibration instrumentation.

Continuous tapes are desired. If necessary, tape changes can be made while stationary.

Manually recorded data will include:

a. Event-time log

b. Checkpoint ID, time, and heading (if known)

c. Odometer reading

d. Speed versus time

e. SAR gimbal position (periodically)

f. Temperature

g. Critical voltages.

9.5 LABORATORY OPERATIONS

Accuracy in van navigation is highly dependent on data recording quality and gyro-bias updates, so, in general, the first operations in a lab rerun will be a data quality check (see Paragraph 9.3.2) followed by a single-position gyro-bias determination (see Paragraph 6.4.2.4.).

The general playback sequence is:

a. Check for data dropouts (gimbal readout comparison)

b. Compute single-position gyro biases (Paragraph 6.4.2(d))

---

*Optional

c. Initialize alignment program

d. Update gyro-bias compensation

e. Run data tape (from van)

f. Enter alignment routine

g. Record alignment data

h. Enter navigation routine

i. Induce failures as specified

j. Record data

k. Terminate run.

The detailed operating procedures are the same as defined in Sections 6 and 7.

9.5.1 Navigation Coordinate System Alignment

Self-alignment will normally be used. However, by inputting the known BB DDH attitude and bypassing the self-alignment routine, the navigation program will initialize (align) to the externally measured coordinates.

The externally measured alignment data will be used as a reference in evaluating self-alignment accuracy.

9.5.2 Input Data

When making computer navigation runs with taped data, the site-dependent data shall be loaded as for laboratory navigation tests.

The input data normally representing BB DDH orientation on the GOERZ ($\underline{\phi}$ R^{E}_{IM}, R^{T}_{L}, and R^{L}_{I}) can be manipulated to represent the inertial orientation of the BB DDH, as measured optically at the beginning of the navigation run. These inputs can be bypassed, as can external alignment and bias update, in van testing with some decrease in accuracy.

9.6 LABORATORY COMPUTER RUN SEQUENCE

This test phase will consist of a rerun of portions of the alignment and navigation tests, Tables 6-I and 7-I, using recorded van data.

The evaluation sequence shall be:

		Reference Test Sequence	
a.	Static alignment	Table 8-I	Sequence 2
b.	Static alignment with failures	Table 8-I	Sequences 3 and 4
c.	Static navigation	Table 7-I	Sequence 2
d.	Straight line navigation	Table 8-II	Sequences 1 and 2
e.	Maneuvering navigation	Table 7-I	Sequence 4
f.	Maneuvering navigation with failures	Table 8-II	Sequences 5 and 6
g.	FDDC tests	Paragraphs 8.3.1 and 8.3.3.2	

The FDDC tests will establish usable filter constants and the failure-detection effectiveness under field conditions.

Figure 9-1 is a flow diagram of the van test phase showing van tests and laboratory navigation runs. If tape changes are necessary in navigation runs, a special procedure for suspending the navigation program in the absence of inputs will be required.

9.7 TEST ANALYSIS AND EVALUATION

9.7.1 Methods

Accuracy, settling times, and failure-detection thresholds and effectiveness will be re-evaluated in an operational environment. The analysis methods will be essentially the same as those for alignment, laboratory alignment, and calibration tests, except for the following:

a. Position reference data will only be available at checkpoints

b. Velocity will be nonzero and reference data will be continuously available

c. Attitude reference available only at the start and the end of run (if optically aligned).

If desired, checkpoint data can be used to RESET inertial positions and velocity data during a computer navigation run.

2

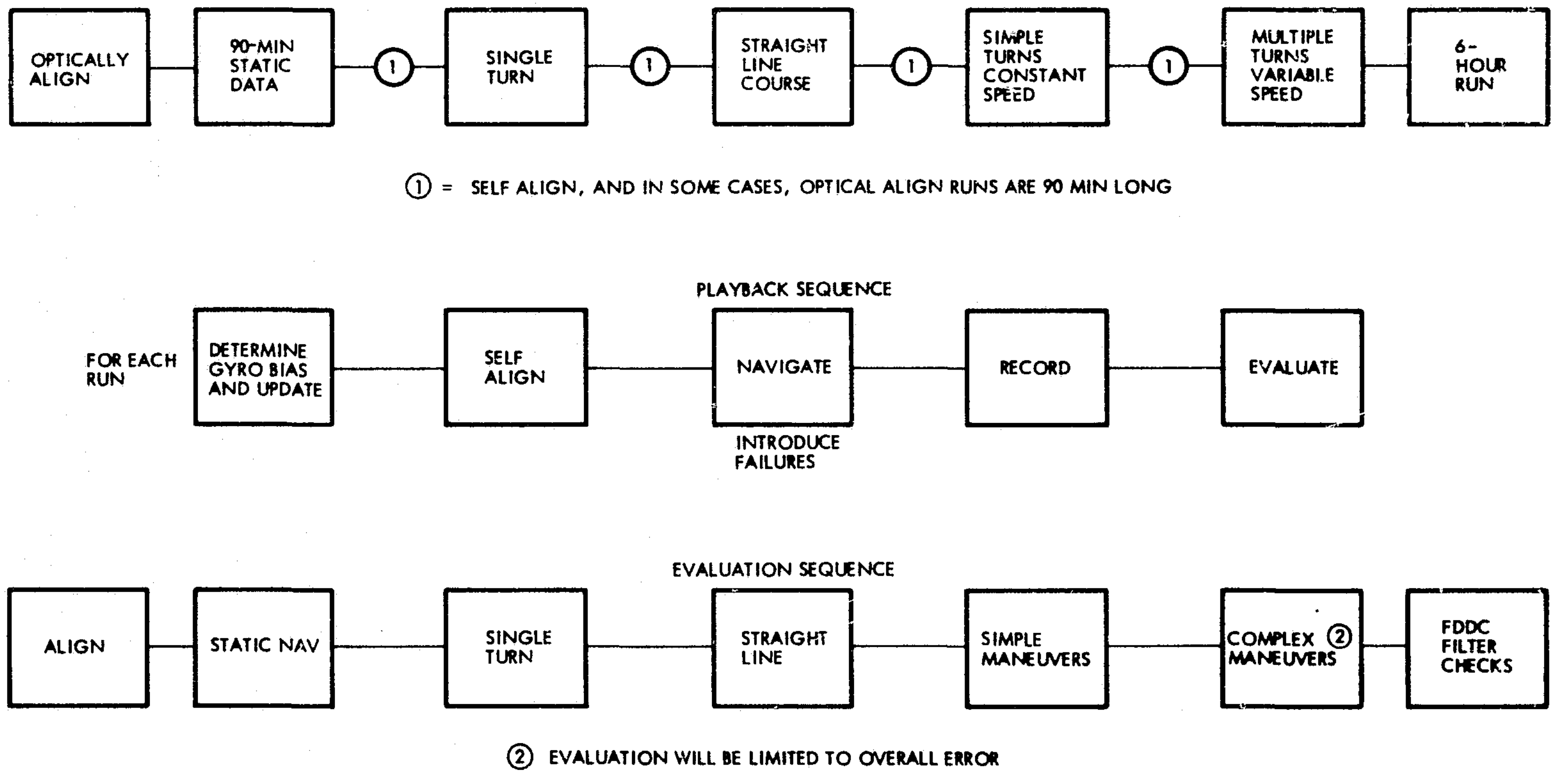

Figure 9-1. Van Test Phase Flow Chart

9.7.2 Checkpoints

Several surveyed checkpoints along the chosen van routes are required. One-hundred meter accuracy will be adequate for BB DDH testing.

9.7.3 Environmental Data

Linear and angular vibration sensors will be available. Preliminary van runs should be made to obtain profiles of vehicle vibration and to select optimum (quiet) operating speeds. Otherwise, detailed (spectral and cross-spectral) analyses of the vibration environment and correlation with BB DDH sensor performance will be performed only if required to resolve test anomalies.

10. FOLLOW-ON TESTING

This section identifies hardware, software, and test evaluation changes that would make logical and worthwhile extensions to the current program.

10.1 HARDWARE CHANGES

- Improved IMU sensors

  Greater accuracy
  Smaller quantization

- Mobile van computer for real-time navigation

- Digital recorder and processor in the mobile van for improved data quality.

10.2 SOFTWARE CHANGES

- Addition of SAR gimbal compensations

- Addition of an on-board gyro bias estimator

- Updated FDDC logic.

10.3 EXTENDED EVALUATION AND ANALYSIS EFFORT

- Comparative evaluation of numerous advanced failure analysis techniques, determining the influence of real-world environments and error mechanisms. Among the proposed strapdown FDDC techniques with significant differences are:

  1. Fifteen threshold technique - ERC/NASA
  2. Total squared error technique - Gilmore/MIT
  3. Maximum likelihood technique - Wilcox/TRW
  4. Boyesian decision theory technique - Gully/MIT
  5. Adaptive technique (RASINS) - Ephgrave/Aerospace

  Emperical confirmation of the validity and relative merits of these schemes is an important next step in the evolution of redundant strapdown guidance (or attitude reference) systems.

- Dynamic error analysis.

10.4 UTILIZATION OF THE REDUNDANT SENSOR PROGRAM EXTENDED CAPABILITY

The existing Redundant Sensor Program is extremely flexible and contains, in addition to the calibration, alignment, navigation, and FDDC routines, elaborate driver and failure simulation routines.

The driver is capable of simulating time variable input profiles (translation and rotation), sinusoidal inputs, and coning. It also computes true position, velocity, and attitude for use in computing the errors in the corresponding outputs of the navigation program.

The program also contains a failure simulation subroutine, capable of corrupting the inputs, whether from the driver or IMU. The errors that can be simulated are:

a. Bias

b. Mass unbalances

c. Misalignments

d. Scale factor errors.

The program is, therefore, capable of complete multisensor simulation and evaluation, and could be used for example, with other failure detection schemes to do testing and analyses far beyond the scope of the current program.

The size of the Honeywell DDP 124 would limit testing such as simultaneous comparison of alternate FDDC techniques. Use of a larger computer should be considered.

APPENDIX A

POSITIONING AND ALIGNMENT OF THE BB DDH AND THE GOERZ TABLE

A. 1 REQUIREMENTS

Rate table rate accuracy	10%
BB DDH alignment to north in positions 4 through 9	3 arc min
Table rotational axis to vertical in positions 1, 2, and 3	3 arc min
Table rotation axis to horizontal in positions 4 through 9*	10 arc sec
BB DDH alignment to table rotation axis	15 arc sec
Table indexing accuracy (error in rotating from positions 4 to 5, etc.)	10 arc sec

A. 2 ALIGNMENT METHOD

A. 2. 1 Use of Bubbles and Cube

Any procedures that produce the required accuracy can be used. The procedures stated yield enough accuracy for the current test phase, but if follow-on testing (Mark I DDH) with the most accuracy that can be obtained is planned, it might be well to use the optical alignment cube in all positions, instead of bubbles as shown here. Use of the cube is complicated with the BB DDH because it is not located near the center of rotation (mass).

A. 2. 2 GOERZ Table Alignment and Stability

Preliminary checks should be made with real or simulated loads to establish the verticality and stability of the table rotational axis, and

*Misalignment to horizontal will affect measured values of the Z-accelerometer bias in positions 4 through 7; b_{AX} and b_{AY} and the Y-accelerometer in positions 8 and 9, b_{EZ}.

adequate load bearing capability and stiffness in positions 4 through 9. The trunnion angle readout that corresponds to a truly horizontal rotational axis for positions 4 through 7 should be established, and then should be established separately for positions 8 and 9.

The azimuth of the rotary axis in positions 4 and 9 (trunnion at 90 deg) must be established. If not 0, the values of theta in Table 5-VII must be revised accordingly.

Thereafter, BB DDH alignment after each mounting and after each reorientation can be accomplished as indicated in the following paragraph.

A. 2. 3 BB DDH Positioning

Position 1

The adjustment to the vertical can be made by two adjustments on the BB DDH base either by using the Y and Z bubble levels or by observing two surfaces of the cube. Azimuth alignment is noncritical.

Position 2

In one plane, the adjustment to the vertical is accomplished by the BB DDH base, and in the other plane by the leveling screw on the mounting fixture.

The bubble levels are not usable in this position and two surfaces of the optical cube should be viewed with the leveled autocollimator for adjustment.

Position 3

The same adjustment is used in position 3 as is used in position 2, except that the X and Y levels can be used.

Position 4

This position would normally be achieved after leveling in position 3 by rotating trunnion to the predetermined angle (A. 2. 1 above) to put the rotary axis horizontal.

If required, leveling will be performed in position 4 in one plane by adjusting the BB DDH base adjustments, and in the other plane by rotating the GOERZ table about the rotary axis.

Azimuth alignment will be accomplished by observing the cube face with an autocollimator and adjusting the mounting fixture adjustment until the Z axis is coincident with the table rotary axis (nominally north).

Positions 5, 6, and 7

These positions are obtained by rotating 90 or 180 deg and by observing the rotary axis pickoff. Optical measurements are not required (after initial configuration of the alignment scheme).

Position 8

Position 8 is obtained by rotating 180 deg about the rotary axis, and accuracy is fixed by the table pickoff accuracy.

Position 9 (Z-axis veritcal)

Leveling is accomplished by mounting adjustments and GOERZ table rotation about the rotary axis. The X and Y levels are usable in this position.

APPENDIX B

INPUT/OUTPUT DATA BY MODES

B.1 INPUT/OUTPUT DATA BY MODES

Paragraph 2.2.3 of Volume II, Reference 3, contains the master lists of all input/output listed alphabetically by both equation symbol and program symbol.

The tables in this appendix list the input/output data appropriate to the alignment and navigation operating modes. The lists may be useful in initial checkout and troubleshooting, but the abbreviated list in Sections 5 through 8 contain the data necessary in normal test operation and evaluation.

Table B-I. Alignment Output Data

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
η_3	NN3	140	23	--	Alignment minor cycle counter
$\underline{u}_A$	AACP	951-953	11	ft/sec^2	Sum of sensed acceleration vector
$\underline{\alpha}$	ALFV	954-956	-3	rad	Sum of sensed rotation vector
$\underline{\gamma}$	GAMV	1002-1004	-4	rad	Computed to account for double integral of rotational rate
η_5	NN5	1031	23	--	Alignment major cycle counter
$\underline{V}_A$	VACV	1005-1007	7	ft/sec	Sensed velocity during 1 major cycle
$\Delta\underline{V}$	DLVV	1008-1010	6	ft/sec	Sensed velocity due to translational motion
$\underline{\alpha}_E$	ALFE	1026-1028	-9	rad	Integral of Earth's rate
$\hat{C}$	CHTX	975-983	-3	--	Attitude update matrix
$\delta\underline{V}_A$	VHTA	1023-1025	7	ft/sec	A priori estimate of $\underline{V}_A$
$\delta\underline{V}_A$	DVVA	1017-1019	6	ft/sec	$\underline{V}_A - \hat{\underline{V}}_A$
y_1	Y1	1034	6	ft/sec	Measurement inputs for Kalman filter
y_2	Y2	1035	6	ft/sec	
$\hat{\theta}_V$	X1	1036	0	rad	
$\hat{\theta}_E$	X2	1037	0	rad	Kalman filter estimates of alignment angles
$\hat{\theta}_N$	X3	1038	0	rad	
$\sqrt{j_{11}}$	SQJ1	1042	-3	rad	
$\sqrt{j_{22}}$	SQJ + 1	1043	-3	rad	Standard deviations (sigma's) of the attitude errors about the local vertical, east and north axes, respectively
$\sqrt{j_{33}}$	SQJ + 2	1044	-3	rad	
$\underline{\theta}'$		832-834	3	rad	Vector of attitude errors about the local level coordinate axes
$\hat{A}$	AHTX	716-724	1	--	Estimated direction cosine matrix

Table B-II. Alignment Input Data

Equation Symbol	Program Symbol	Relative Location	Scale	Program Nominal Value	Units	Definition
$\hat{\phi}_D$	PHTD	238	3	0.6041388	rad	Estimated initial geodetic latitude
$\hat{\theta}_L$	TLHT	247	3	4.770529	rad	
$\hat{\underline{\phi}}$	PHIL	233-235	3	0	rad	Estimated $\underline{\phi}$
$\hat{A}_Z$	AZHT	1	3	0	rad	Initial azimuth estimated
R_{IM}^{E}(3x3)	RIMX	68-76	0	See below	--	Rotation matrix from the table inner member to the ERSA coordinate system
$R_{IM}^{E} = \begin{matrix} -1. & 0. & 0 \\ 0. & 1. & 0 \\ 0. & 0. & -1 \end{matrix}$						
R_L^T (3x3)	RLTX	77-85	0	1(Ident)	--	Rotation from VEN to table top coordinate
R_I^L (3x3)	RILX	86-94	0	See below	--	Rotation matrix from inertial to VEN coordinates at the point of initialization
$R_I^L = \begin{matrix} -0.03299913 & +0.56709424 & 0.8229916 \\ 0.99831126 & 0.05809159 & 0 \\ -0.04780889 & 0.82160178 & -0.56805354 \end{matrix}$						
Ω_E	OMGE	1455	-13	7.2921569E-5	rad/sec	Earth's rate
Δtg	DTG4	1457	-4	0.04	sec	Alignment minor cycle time
N_4	N4	141	23	25	--	Number of minor cycles per major cycles during alignment
σ_{11}	SG11	254	-3	0.2384E-6	rad	
σ_{22}	SG22	255	-3	0.2384E-6	rad	Initial values for state-noise covariance matrix
σ_{33}	SG33	256	-3	0.2384E-6	rad	
σ_A	SIGA	257	-7	0.4	ft/sec/pulse	Quantization noise
σ_1	SIG1	258	-3	0.02	rad	
σ_2	SIG2	259	-3	0.02	rad	Initial misalignment estimate
σ_3	SIG3	260	-3	0.02	rad	
g_A	GA	1478	6	32.139929	ft/sec^2	Earth's surface gravity
N_6	NN6	250	23	1800	--	Number of major cycles for alignment

Table B-III. Navigation Outputs

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
t_N	TNCP	682	15	sec	Navigation time
$\hat{\underline{V}}$	VHTV	688-690	13	ft/sec	Estimated inertial velocity vector
$\hat{\underline{Y}}$	RHTV	691-693	25	ft	Estimated position vector in ECI
$\hat{\underline{u}}_r$	URHT	694-696	1	--	Estimated unit position vector
$\hat{A}_{LT}$	ALTH	7	25	ft	Estimated altitude
$\hat{\theta}_L$	TLHT	247	3	rad	Estimated longitude
$\hat{\phi}_D$	PHTD	238	3	rad	Estimated goedetic latitude
$\hat{\underline{V}}_E$	VEHT	793-795	13	ft/sec	Estimated velocity vector relative to earth in estimated geodetic local level coordinates
$\hat{V}_R$	VRHT	792	13	ft/sec	Magnitude of $\underline{V}_E$
$\hat{\gamma}$	GMHT	796	3	rad	Estimated azimuth of velocity vector (measured clockwise from north)
$\hat{\underline{a}}$	AHAC	900-902	9	ft/sec^2	Estimated inertial acceleration in inertial coordinates
$\hat{\underline{a}}^L$	ACCH	797-799	9	ft/sec^2	Estimated inertial acceleration in estimated local level coordinates
$\hat{\underline{\omega}}_b^L$	WBLH	800-802	1	rad/sec	Estimated rotational rate vector relative to earth expressed in estimated local level coordinates
$\hat{A}$	AHTX	716-724	1	--	Estimated direction cosine matrix (3 x 3)
$\underline{\theta}$	THTV	803-805	-2	rad	Attitude error vector about the body axes
$\underline{\theta}'$	THTP	806-808	-2	rad	Attitude error vector about the true local level coordinate axes
$\delta\phi_D$	DLPD	810	3	rad	Latitude error
$\delta\theta_L$	DLTL	811	3	rad	Longitude error
δ_{ALT}	DLAL	812	25	ft	Altitude error
$\delta\underline{V}$	DLTV	813-815	13	ft/sec	Error in $\underline{V}_E$

Table B-III. Navigation Outputs (Continued)

Equation Symbol	Program Symbol	Relative Location	Scale	Units	Definition
δV	DELV	816	13	ft/sec	Error in $\hat{V}_R$
$\delta\gamma$	DGAM	817	3	rad	Error in $\hat{\gamma}$
$\delta\gamma'_E$	DREP		23	ft	Estimated position error in east direction
$\delta\gamma'_N$	DRNP		23	ft	Estimated position error in north direction
tg	TG	861	15	sec	Time since the last navigation or attitude update initialization
η_1	N1	872	23	--	Number of attitude update since the last A matrix orthonormally correction
η_A	NACP	865	23	--	Number of attitude update cycles since initialization
$p'a_i$	APUL	841-846	15	pulses	Accelerometer output pulses (6 x 1) (40 msec sums)
$\hat{a}_{ai}$	AHTA	725-730	8	ft/sec^2	Sensed and compensated acceleration (6 x 1)
$\underline{\hat{a}}_s$	AHTS	835-837	8	ft/sec^2	Estimated sensed acceleration in body coordinates (3 x 1)
$p'g_i$	GPUL	847-852	15	pulses	Gyro output pulses (6 x 1) (40 msec sums)
$\hat{\omega}gi$	ØHTG	733-738	1(-4)	rad/sac	Compensated gyro output rates (6 x 1)
$\underline{\hat{\omega}}s$	WHTS	838-840	1(-4)	rad/sec	Estimated sensed rotation rates in body coordinates (3 x 1)
$\Delta\underline{\hat{\alpha}}$	DALH	866-868	-5	rad	Estimated sensed rotation in a minor cycle (3 x 1)
Φ	PHIX	745-753	-5	rad	Estimated rotation matrix which relates the body-fixed coordinate system at the end of an attitude update cycle with that of the beginning of the cycle (3 x 3)
E1	E1	678	-5	--	
E3	E3	679	-5	--	A matrix orthonormalization correction terms
E13	E13	754	1	--	
$\underline{\hat{a}}'_s$	AHSP	897-899	8	ft/sec^2	Estimated sensed acceleration vector in estimated inertial coordinates (3 x 1)
$\Delta\underline{V}'_s$	DVSP	700-702	9	ft/sec	Accumulated sensed velocity estimate in inertial coordinates (3 x 1)

Table B-IV. Navigation Input Data

Equation Symbol	Program Symbol	Relative Location	Scale	Nominal Value	Units	Definition
$\hat{\phi}_D$	PHTD	238	3	0.6041388	rad	Estimated initial geodetic latitude
$\hat{\theta}_L$	TLHT	247	3	4.7705299	rad	Estimated initial longitude
$\hat{A}_Z$	AZHT	1	3	0	rad	Initial azimuth estimated
$\underline{\phi}$	PHIV	65-67	3	--	rad	Rotation angles defined as follows for each component:
ϕ_1	PHIV	65	3	1.5707963	rad	Rotation angle of the innermost table member with respect to the middle table
ϕ_2	PHIV+	66	3	1.5707963	rad	Rotation angle of the middle table member with respect to the outermost table member
ϕ_3	PHIV+2	67	3	0	rad	Rotation angle of the outermost table member relative to the table top
$R_{IM}^{E}(3x3)$	RIMX	68-76	0	See below	--	Rotation matrix from the innermost table member to the ERSA coordinate system
$R_{IM}^{E} = \begin{matrix} -1, & 0, & 0 \\ 0, & 1, & 0 \\ 0, & 0, & -1 \end{matrix}$						
$R_L^T(3x3)$	RLTX	77-85	0	I(Ident)	--	Rotation from VEN to table top coordinates
$R_I^L(3x3)$	RILX	86-94	0	See below	--	Rotation matrix from inertial to VEN coordinates at the point of initialization
$R_I^L = \begin{matrix} 0.03299913 & +0.56709424 & 0.8229916 \\ 0.99831126 & 0.05809159 & 0 \\ -0.04780889 & 0.82160178 & -0.56805354 \end{matrix}$						
$\hat{\underline{\phi}}$	PHIL	233-235	3	0	rad	Estimated $\underline{\phi}$
g_A	GA	1478	23	32.139929	ft/sec^2	Gravity at test site
Δt_I	DLTI	2	-4	0.04	sec	Minor cycle time during initialization
Δtgo	DITGO	13	2	0.04	sec	Minor cycle time during navigation

Table B-IV. Navigation Input Data (Continued)

Equation Symbol	Program Symbol	Relative Location	Scale	Nominal Value	Unit	Definition
N_N	NNCP	3	10	25	--	Number of minor cycles per major cycle
n_2	N2	130	23	10	--	Number of minor cycles between A matrix
N_1	NCP1	138	23	25	--	Number of minor cycles for initialization
b1	B1	1462	-8	0.3369208E-2	--	Constants in $\hat{\nu}_{SL}$ computation
b2	B2	1463	-15	0.1688446E-4	--	Constants in $\hat{\nu}_{SL}$ computation
b3	B3	1464	-15	0.224762E-4	--	Constants in $\hat{\phi}_c$ computation
b4	B4	1465	-7	0.671589E-2	--	Constants in $\hat{\phi}_c$ computation
b5	B5	1466	-7	0.669342E-2	--	Constants in $\hat{\phi}_o$ computation
b6	B6	1467	-15	0.2247623E-4	--	Constants in $\hat{\phi}_o$ computation
ΩE	ØMGE	1455	-13	7.2921569E-5	rad/sec	Earth rate
Gm	GM(MUE)	1454	54	-1.4076539	H^3/sec^2	Earth gravity constants
$Re(\bar{A})$	RE(ABAR)	1460	25	2.0925738E7	tt	Average radius of earth at equator
-	STPT	266	15	32.767	sec	Navigation stop time
a_r	AR	237	-4	-0.03124		Altitude damping constants
a_v	AV	236	-5	0		

Table B-V is a matrix of raw gyro and accelerometer pulse accumulations during the calibration static tests. These may be useful in troubleshooting.

Table B-V. Matrix of Raw Gyro and Accelerometer Pulse Accumulations

m_{AXU}	MAXU	556-561	23	Counts	Raw accelerometer pulse, X up
m_{AXD}	MAXD	562-567	23	Counts	Raw accelerometer pulse, X down
m_{AYU}	MAYU	568-573	23	Counts	Raw accelerometer pulse, Y up
m_{AYD}	MAYD	574-579	23	Counts	Raw accelerometer pulse, Y down
m_{AZU}	MAZU	580-585	23	Counts	Raw accelerometer pulse, Z up
m_{AZD}	MAZD	586-591	23	Counts	Raw accelerometer pulse, Z down
n_{AXU}	NAXU	592-597	23	Counts	Raw gyro pulse, X up
n_{AXD}	NAXD	598-603	23	Counts	Raw gyro pulse, X down
n_{AYU}	NAYU	604-609	23	Counts	Raw gyro pulse, Y up
n_{AYD}	NAYD	610-615	23	Counts	Raw gyro pulse, Y down
n_{AZU}	NAZU	616-621	23	Counts	Raw gyro pulse, Z up
n_{AZD}	NAZD	622-627	23	Counts	Raw gyro pulze, Z down

B.2 TABLE ALIGNMENT MATRICES

The coordinate conversion matrices used to input the BB DDH orientation to the RSP are defined in Appendix A (A-13) Volume I, Reference 3.

The values for these matrices for each test position (as defined in Table 5-II) are given in Table B-VI.

Table B-VI. Test Table Orientation Matrices

Position	R_+^+	R_{IM}^E	ϕ_1	ϕ_2	ϕ_3
1	100 010 001	-100 010 00-1	$\pi/2$	$\pi/2$	0
2	001	00-1	$\pi/2$	0	0
3	001	00-1	0	0	0
4	001 010 -100	00-1	0	0	0
5	-100	00-1	0	0	π
6	-100	00-1	0	0	$\pi/2$
7	-100	00-1	0	0	$-\pi/2$
8	-100	00-1	$\pi/2$	0	$-\pi/2$
9	-100	00-1	$\pi/2$	0	$\pi/2$

The test table rotary axis angle ϕ_3, is defined as 0 when the BB DDH is mounted in position 3 with the X axis pointed south. The geodetic latitude and longitude of the MSFC inertial test station are:

γ_D Latitude 0.60413881 rad N

θ_D Longitude 4.7705299 rad E (86°40'11'')

The corresponding R_I^L matrix is:

-0.03299913	+0.56709424	0.8229916
0.99831126	0.05809159	0
-0.047808891	0.82160178	-0.56805354

Note: In Volume I, Reference 3, Page A-13, there is a sign error in the matrix equation for R_I^L from which this matrix was computed; the value in row 1, column 2, is $-\sin \gamma_D \sin \theta_L$.

There is also a sign error on Page A-15 in the equation for R_T^{IM}. The expression in row 2, column 2, should be $\sin\phi_1 \sin\phi_2 \sin\phi 3 + \cos\phi 1 \cos\phi 3$

B.3 NOMINAL DIRECTION COSINE AND C MATRICES

Equation Symbol	Program Symbol	Relative Location	Scale	Nominal Value	
$[C]_g$	FCGM	1210,1299	0	Note 1	15x6 gyro C matrix
ag	FAGM	1300-1317	1	Note 2	Gryo direction cosines
$[C]a$	FCAM	1318-1407	0	Not used	15x6 accelerometer, C matrix
aa	FAAM	1408-1425	1	See Note 3	Accelerometer direction cosines

Note 1: Gyro C Matrix (15x6)

0	0	-a	a	-b	-b
0	-a	0	b	-a	b
0	-a	b	0	-b	a
0	b	-a	b	0	-a
0	-b	-b	a	-a	0
a	0	0	-b	-b	a
a	0	-b	0	-a	b
-b	0	-b	a	0	-a
b	0	-a	b	-a	0
-b	b	0	0	a	-a
a	b	0	-a	0	b
-b	-a	0	a	-b	0
-b	-a	a	0	0	b
a	b	-a	0	-b	0
a	a	-b	-b	0	0

Note 2: Gryo Direction Cosines

b	0	a
b	0	-a
a	-b	0
a	b	0
0	a	b
0	a	-b

b = .52573111
a = .8506508

Note 3: Accelerometer Direction Cosines

0	0	1
0	0	0
1	0	0
0	0	0
0	1	0

APPENDIX C

INPUT/OUTPUT TAPE FORMATS

C.1 TAPE OUTPUT FORMAT

During a real-time mode of RS program operation, a binary output tape containing output information for the run is recorded. Since this is a binary tape, the data must be converted to a proper BCD form before they can be output to any print output device.

Output parameters to be recorded on a tape are selected before a run. N words of minor cycle output data ($N \leq 20$) and M words of major cycle output data ($M \leq 60$) are selected. Twenty-five cycles of minor cycle data and a cycle of major cycle data are recorded into fourteen records repeated for the duration of a run. A record of data consists of L words of binary data preceeded by a record gap. Fourteen records are written on a magnetic tape as depicted in Figure C-1.

The number of words in a record, L, is determined by the tape output routine as a function of M and N, the numbers of major and minor output words. L is determined by the following equation.

$$L = 2 \times [\text{larger of } N \text{ or } P]$$

where

N = number of minor cycle output words

M = number of major cycle output words

$P = \frac{M}{3}$ when there is no remainder
(M, N, and P are integers).

When M/3 is not an integer, P is rounded to the next integer >M/3. When N is larger than P, a major cycle output block consists of 3N words, 2N words of which are in Record 1 and N words in the first half of Record 2. Only M words of 3N words of major cycle block contain useful information. The rest are filled by whatever was present in the tape buffer. The first minor cycle output words start from the N+1th word of Record 2. The remaining minor cycle outputs are recorded on the rest of the records as depicted on the figure.

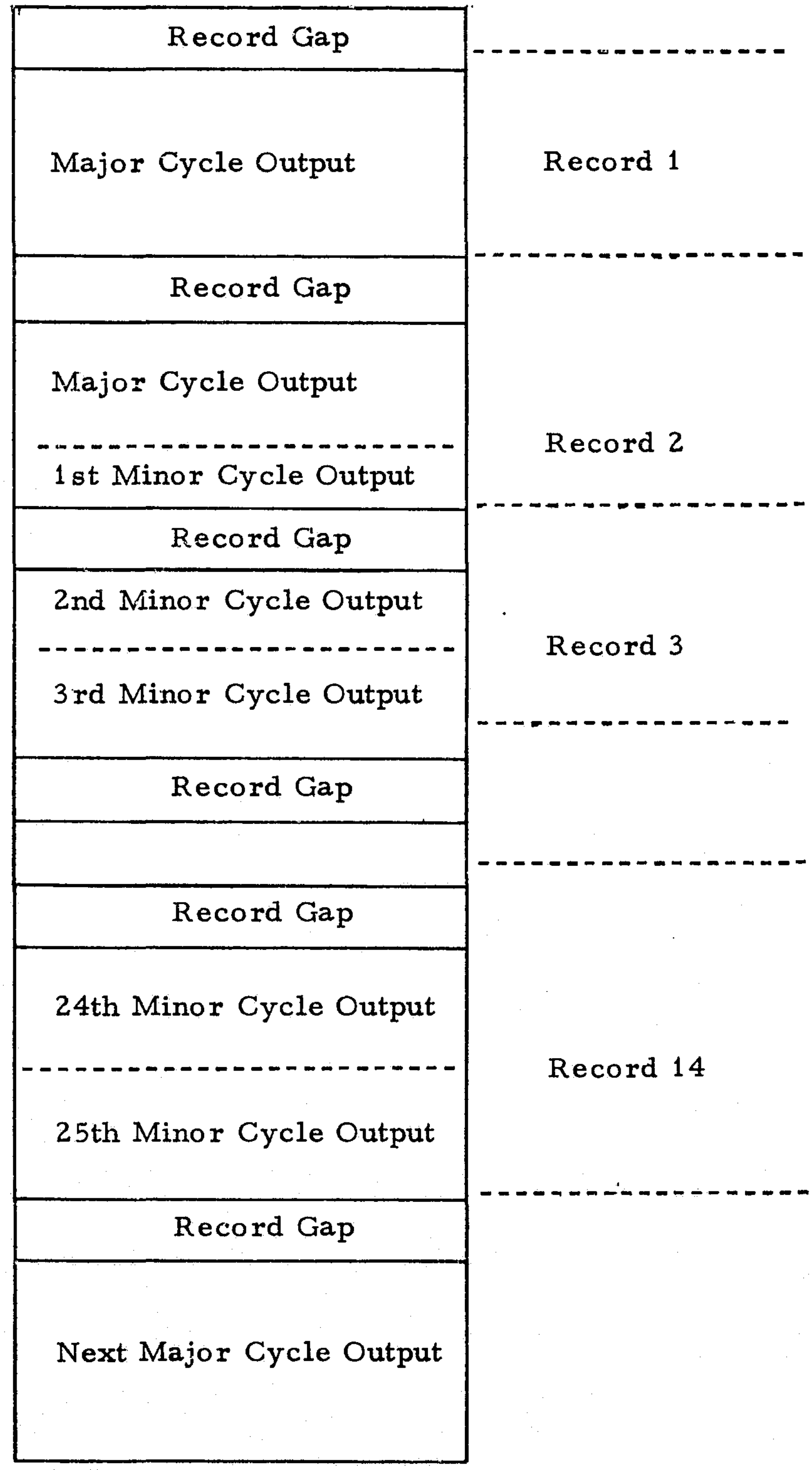

Figure C-1. Tape Output Format

When P is larger than N, a major cycle output block consists of 3P words, 2P words of which are in Record 1 and P words in the first half of Record 2. When 3P is larger than M, 3P-M (1 or 2) words of meaningless data are stored to fill the block. For each minor cycle block of data, P-N words of meaningless data are stored to fill the block. For each minor cycle block of data, P-N words of meaningless data are stored to make each minor cycle block equal to P words. The manner in which they are recorded is as depicted in Figure C-1.

The scalings for these output data are dependent on the selections of output parameter words which were made at the beginning of a run. Therefore, the program which converts these binary data to their decimal equivalents must have a capability to input various scale factors to be used for the conversions as well as the numbers of words, N and M, for each record.

The order of output (minor cycle and major cycle) is exactly as specified by the OPWs. Note that if fewer than 20 minor cycle words are specified, the remainder must be filled with 0 OPWs before starting the major cycle OPWs. The program determines how many words are to be output by checking for 0 OPWs or when 20 (or 60) is reached, whichever occurs first.

C.2 OUTPUT DURING THE SIMULATION MODE

There is no real-time restriction during the simulation mode (the Driver mode or tape input mode). Up to 300 values of selected parameters may be printed out by the typewriter or stored on the magnetic tape in the BCD format. The frequencies of output may be changed during a run, or additional lists of output parameter words may be added to the existing list during the run. The details of how to specify the output device, print frequency, and the output parameter words are described in Paragraphs 4.2.6.1 and 4.2.6.2. Subsection 4.3 describes the procedure necessary to make the online changes to the output operation. These options are called Sense Switch 6 options and are only applicable during the simulation mode.

C.3 TAPE INPUT FORMAT

An input tape may be used with the RS program in lieu of real-time IFE inputs or driver generated inputs. The input tape must have been created according to the following rules:

a. Binary mode

b. Record size of 18 DDP-124 words

c. The first six words correspond to gyros one through six

d. The accelerometer pulses are in words seven, nine, and eleven

e. The table angle, scaled at +15, is in word 13

f. The gyro monitor discrete is in word 14

g. The sampling frequency with which the data were recorded must have been an integral multiple of the normal minor cycle frequency (25 cps). See Paragraph 4.2.4.2 for a description of the RCT counter.

APPENDIX D

PROGRAM MODIFICATIONS

The following program modifications refer to the listing generated at MSFC on 9 December 1971. In all cases, the names given must be included.

D.1 CHANGES DESIGNATED AS TBD IN REFERENCE 5

Dec.Sequence Number	Name	New Value	Comments
$NSRT 5716,			
	RIMX	OCT 77777777	BO R(IM)E 3x3 I0
		OCT 0	12
		OCT 0	13
		OCT 0	21
		OCT 37777777	22
		OCT 0	23
		OCT 0	31
		OCT 0	32
		OCT 77777777	33
$OMIT 5716, 5724			
$NSRT 5734,			
	RILX	DEC -0.03299913B0	R(I)L 3x3 I0
		DEC 0.56709424B0	12
		DEC 0.8229916B0	13
		DEC 0.99831126B0	21
		DEC 0.05809159B0	22
		DEC 0	23
		DEC -0.047808891B0	31
		DEC 0.82160178B0	32
$OMIT 5734, 5742		DEC -0.56805354	33
$NSRT 5715,			
	PHIV	DEC 1.5707963B3	B3 I0
		DEC 1.5707963B3	PI/2
		DEC 0	
$OMIT 5715, 5715			

Dec. Sequence Number	Name	New Value	Comments
$NSRT 5852,			
	AV	DEC -0.03124B-5*	B-5 AV N6
	AR	DEC 0*	B-4 AR N6
$OMIT 5852, 5853			
$NSRT 6492,			
		DEC 0.6041388B3	Latitude (rad)
		DEC 4.7705299B3	Longitude (rad)
$OMIT 6492, 6493			
$NSRT 6520,			
	GA	DEC 32.139929B6	Local G
$OMIT 6520, 6520			

D.2 ACCELEROMETER DELETION (NEW CHANGE)

The following change will cause FDDC to process only accelerometers 1, 3, and 5.

Name	Change	Comments
$NSRT 71,	LDA = '00000052 STA FSA	Set Accelerometer Status flag
$NSRT 3099,	JST DLAY	Wait for interrupt
$OMIT 3099, 3099		

D.3 DISCARD OF FIRST SAMPLE (NEW CHANGE)

The following changes will cause the first 40 msec sample to be discarded, so that only a full 40 msec worth of data will be processed rather than some portion of 40 msec.

Name	Change		Comments
$NSRT 6584,			
	JPL	EXE1	
	CRA		
	STA	MINC	Turn off First-Time flag
	STA	STPF	Set Stop flag
	JST	DLAY	Wait for interrupt
	JMP*	D00	Go

*These changes should not be made until all other changes are checked out.

Dec. Sequence Number	Name	New Value		Comments
	IIFE	NOP		Initialize IFE
		LDA = '40000000		First-Time flag
		STA	MINC	Hide it in minor cycle counter
		LDA	STPF	
		JZE	*-1	Wait
		JMP*	IIFE	
$NSRT 6797,				
		JST	IIFE	
$OMIT 6797, 6797				

D.4 SELECTION OF PRINCIPAL ACCELEROMETER BIAS (NEW CHANGE)

This change selects one of the three-bias measurements in each accelerometer channel as the principal bias term, to be used for compensations. See Paragraph 5.7.1 for discussion.

Name	Change		Comments
$NSRT 7946,			
	LDB	PAZ	B8
	MPY	ASFK	B0, B8, LBAZ
	LLS	3	B5
	RND		
	STA	LBA	B5, LBA = LBAZ
	LDB	PAX+2	B8, PCX
	MPY	ASFK+2	B0, B8, LBCX
	LLS	3	
	RND		
	STA	LBA+2	B5, LBC = LBCX
	LDB	PAX+4	B8, PEX
	MPY	ASFK+4	B0, B8, LBEX
	LLS	3	
	RND		
	STA	LBA+4	B5, LBE = LBEX

D.5 SUMMARY OF ALL CHANGES

The following are all the updates to go from the 31 December 1969 TRW source tape (this was the tape generated at MSFC on Wednesday, 8 December 1971) to the complete MSFC compatible source tape. This list includes all recommended changes from References 2 and 5, and this plan.

Name	Change	Comments
$NSRT	71,	
	LDA = '00000052	Set Accelerometer Status flag
	STA FSA	
$NSRT	96,	
RD11	JMP DXX-3	
$OMIT 96, 96		
$NSRT	124,	
	LDA = '00010000	1B11
$OMIT	124, 124	
$NSRT	128,	
	LDA = '00100000	1B8
$OMIT	128, 128	
$NSRT	2378,	
	LRS 5	Rescale to B15
$NSRT	2790,	
	MPY KHTA+6, 1	B19 to delta V units
	LLS 11	B8
$OMIT	2790, 2791	
$NSRT	2825,	
	LLS 4	
$OMIT	2825, 2825	
$NSRT	3098,	
	JST DLAY	Wait for interrupt
$OMIT	3098, 3098	
$NSRT	3104,	
	JMP G82	
$OMIT	3104, 3104	

Name	Change		Comments
$NSRT	3223,		
G82	LDA	DRVE	
$OMIT	3223, 3223		
$NSRT	3919,		
	JMP	A11+6	
$OMIT	3919, 3919		
$NSRT	3960,		
	JMP	LDT3-6	Go back to real time
$OMIT	3960, 3960		
$NSRT	4005,		
	JMP	FDCA	Point C
$OMIT	4005, 4005		
$NSRT	4978,		
	JMP	PD6	
$NSRT	4981,		
	JMP	D00	
$OMIT	4981, 4981		
$NSRT	5008,		
SFTA	DEC	-3, -3, -3, 0, -3, -3, -3, +12, -10	
$OMIT	5008, 5008		
$NSRT	5693,		
QA	DEC	0.4B0	Accelerometer quantity
QG	DEC	0.260312964E-4B-14	Gyro quantity
$OMIT	5693, 5694		
$NSRT	5714,		
PHIV	DEC	1.5707963B3	B3 I0
	DEC	1.5707963B3	PI/2
	DEC	0	
RIMX	OCT	77777777	B0 R(IM)E 3x3 I0
	OCT	0	12
	OCT	0	13
	OCT	0	21

Name	Change		Comments
	OCT	37777777	22 1.0
	OCT	0	23
	OCT	0	31
	OCT	0	32
	OCT	77777777	33 -1.0
$OMIT	5714, 5723		
$NSRT	5733,		
RILX	DEC	0.03299913B0	R(I)L 3x3 I0
	DEC	0.56709424	12
	DEC	0.8229916	13
	DEC	0.99831126	21
	DEC	0.05809159	22
	DEC	0	23
	DEC	0.04780889	31
	DEC	0.82160178	32
	DEC	-0.56805354	33
KHTA	DEC	10.0B4	B4 K-HAT(A) G1 6x1
	DEC	10.0B4	
	DEC	10.0B4	
	DEC	10.0B4	
	DEC	10.0B4	
	DEC	10.0B4	
KHTG	DEC	0.59920538E-3B-10	B10 K-HAT(G) G2 6x1
	DEC		
	DEC		
	DEC		
	DEC		
	DEC	0.59920538E-3B-10	
$OMIT	5733, 5753		
$NSRT	5772,		
DHTA	DEC	0	B15 D-HAT(A) I1, G1
	DEC	0	

Name	Change		Comments
	DEC	0	
	DEC	0	
	DEC	0	
	DEC	0	
DHTG	DEC	0	B15 D-HAT(G) I1, G2
	DEC	0	
	DEC	0	
	DEC	0	
	DEC	0	
	DEC	0	
$OMIT	5772, 5783		
$NSRT	5851,		
AV	DEC	-0.03124B-5	AV N6
AR	DEC	0	B-4 AR N6
$OMIT	5851, 5852		
$NSRT	5870,		
SIGA	DEC	0.4B0	B0 A7, KFTR
SIG1	DEC	0.02B-3	B-3 IA8, KFTR
SIG2	DEC	0.02B-3	B-3 IA8, KFTR
SIG3	DEC	0.02B-3	B-3 IA8, KFTR
$OMIT	5870, 5873		
$NSRT	6484,		
TYFL	DEC	1B23	Dump on TW
$OMIT	6484, 6484		
$NSRT	6491,		
	DEC	0.6041388B3	Phi (D)
	DEC	4.7705299B3	Theta (L)
$OMIT	6491, 6492		
$NSRT	6519,		
GA	DEC	32.139929B6	B6 local grav.
$OMIT	6519, 6519		
$NSRT	6525,		
BIAS	DEC	0	Pulses equiv. to 0 G
	DEC	0	Gyro bias

Name	Change		Comments
$OMIT	6525, 6526		
$NSRT	6583,		
	JPL	EXE 1	
	CRA		A = 0
	STA	MINC	First pass off
	STA	STPF	Delay flag on
	JST	DLAY	Wait for next interrupt
	JMP*	D00	To II1
IIFE	NOP		Skip first 40 msec
	LDA =	'40000000	First-Pass flag
	STA	MINC	Hide it in the minor cycle counter
	JZE	*-1	
	JMP*	IIFE	
$NSRT	6596,		
	LDA	BUF1+13	Internal Monitor flag for gyro
	STA	FFDG	
$NSRT	6636,		
*	Write EOF on real-time data tape		
	LDA	IPOS+80	Was tape used
	JZE	*+7	No, exit
	OCP	'06000	Enable DMA-1
	LDA	TFLG	Which unit
	JZE	*+3	
	OCP	'20402	Unit 2
	JMP	*+2	
	OCP	'20401	Unit 1
$NSRT	6639,		
	SKS	'40	Is Sense Switch 6 on
	JMP	DXX-3	Yes, use OPWs in memory
$NSRT	6640,		
	SKS	'40	Is Sense Switch 6 on
	JMP	EXE2+5	Yes, dump OPW and stop

Name	Change	Comments
$NSRT	6754,	
	STA TS1+1	Save A
	IAB	B to A
	JZE *+2	
	LDA = 1	
	ADD TS1+1	
$OMIT	6754, 6755	
$NSRT	6781,	
	JST IIFE	Initialize IFE
$OMIT	6781, 6781	
$NSRT	7037,	
	SKS '26002	Exit if DMA-3 is busy
	JMP NOUT+8	Busy, so exit
$OMIT	7037, 7038	
$NSRT	7041,	
	OCP '06002	DMA-3
$OMIT	7041, 7041	
$NSRT	7050,	
	JMP *-2	
$OMIT	7050, 7050	
$NSRT	7489,	
GBAS	DEC 0	Gryo bias
ABAS	DEC 0	Acceleration bias
$OMIT	7489, 7490	
$NSRT	7520,	
	JMP *+2	
$OMIT	7520, 7520	
$NSRT	7563,	
	LRS 0	B0
	DIV DTG4	B-4 to B4
	STB KHTA+6, 1	B4 FPS/40 msec
$OMIT	7563, 7565	
$NSRT	7568,	
	LRS 14	B19
$OMIT	7568,7568	

Name	Change		Comments
$NSRT	7614,		
	LLS	0	
$OMIT	7614, 7614		
$NSRT	7878,		
	LDA	= '00020000	1B10
$OMIT	7878, 7878		
$NSRT	7884,		
	LLS	10	
$OMIT	7884, 7884		
$NSRT	7889,		
	LLS	10	
$OMIT	7889, 7889		
$NSRT	7894,		
	LLS	10	
$OMIT	7894, 7894		
$NSRT	7946,		
	LDB	PAZ	B8
	MPY	ASFK	B0, B8, LBAZ
	LLS	3	B5
	RND		
	STA	LBA	B5, LBA = LBAZ
	LDB	PAX+2	B8, PCX
	MPY	ASFK+2	B0, B8, LBCX
	LLS	3	
	RND		
	STA	LBA+2	B5, LBC = LBCX
	LDB	PAX+4	B8, PEX
	MPY	ASFK+4	B0, B8, LBEX
	LLS	3	
	RND		
	STA	LBA+4	B5, LBE = LBEX
$DONE			

D. 6 ADDENDUM

The nominal values for the main program gyro and accelerometer direction cosine matrices must be revised to the values given in Paragraph B. 3. After determination of the exact values of these matrices are defined by the calibration program, these should be used to replace the main program nominal values.